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THESIS

AIR-LAND BATTLE INTERDICTION MODEL
CORPS COMMUNICATION MODULE

by

Daniel R. Alexander

June 1984

Thesis Advisor: Arthur Schoenstadt

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This thesis provides the detailed concepts and methodology required to simulate the Corps Communications Module (CM) portion of the Air-Land Interdiction Model. The Communications Module is a closed architecture with rule-based decision making, network design, threat play, and net congestion that closely simulates the environment U.S. Army communications systems face in supporting Corps and selected Theater level

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Airland Battle Interdiction Model
Corps Communication Module

by

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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June 1984

ABSTRACT

This thesis provides the detailed concepts and methodology required to simulate the Corps Communications Module (CM) portion of the Air-Land Interdiction Model.

The Communications Module is a closed architecture with rule-based decision making, network design, threat play, and net congestion that closely simulates the environment that U.S. Army communication systems face in supporting Corps and selected Theater level units in Europe. The common decision making thread is a Communications Generalized Value System (CGVS) which determines current assets value based on past, present, and potential usage. The CGVS provides a basis for quantitative and qualitative decision making that can be studied for cause and effect relationships by means of audit trails.

The Communications Module analyzes Corps communications in high resolution detail while dealing with the problems of friendly net congestion compounded by enemy interdiction. When operational, the Communications Module will give US Army communicators a realistic training and architectural planning tool.

TABLE OF CONTENTS

I. MOTIVATION FOR HAVING A COMMUNICATIONS MODULE . . 12

A. PURPOSE 12

B. FITTING INTO THE AIRLAND RESEARCH MODEL . . . 13

C. SCOPE 14

II. OVERALL COMMUNICATIONS MODULE CONCEPT 15

A. INTRODUCTION 15

B. CONCEPT 15

III. COMMUNICATION DEGRADATION SUBMODULE 24

A. INTRODUCTION 24

1. Environmental Degradation 24

2. Red Force Interdiction 27

3. Blue Force Net Congestion Degradation . . 27

B. RED FORCE INTERDICTION DEGRADATION 28

1. Introduction 28

2. Soviet Strategic and Tactical Priorities 29

3. Soviet Intentions to Interdict BF Communications 30

4. Details of a Potential RF Interdiction Module (RFIM) 33

C. BLUE FORCE NETWORK CONGESTION AND DEGRADATION 42

1. Introduction 42

2. Message Traffic Database 43

3. General Scheme of Operation 47

4. Analytics 48

5. Overview Of Congestion Algorithm 49

    6. Theoretical Justification for Traffic Analytics 54
    7. High Resolution Candidate 56

IV. COMMUNICATIONS GENERALIZED VALUE SYSTEM 67
  A. INTRODUCTION 67
  B. CGVS CONCEPT 68
    1. Static Value Determination 72
    2. Dynamic Value Determination 75

V. RULE-BASED DECISION SUBMODULES 80
  A. INTRODUCTION 80
  B. CLOSED LOOP DECISION MAKING 80
    1. Selecting Communication Alternatives in a Combat Environment. 80
    2. Results and Discussion of Automated "Closed Loop" Decision Model 85
  C. USER TO USER ROUTING DECISION 90
  D. REROUTE SUBMODULE 91
    1. Single Channel 93
    2. Multichannel 94
  E. RECONSTITUTION SUBMODULE 95

VI. SUMMARY AND CONCLUSIONS 97

APPENDIX A: VARIABLE RESOLUTION DIAGRAMS FOR COMMUNICATION MODULE 99

APPENDIX B: GLOSSARY OF TERMS AND ACRONYMS 106
  A. TERMS 106
  B. ACRONYMS 110

APPENDIX C: BRIEFING ON MULTI-ATTRIBUTE DECISION MAKING 113

APPENDIX D: COMMAND STRUCTURE AND FORCE DEPLOYMENT INTACS AND COMSR 120

LIST OF REFERENCES 126

INITIAL DISTRIBUTION LIST 128

LIST OF TABLES

I. Communication Submodules 18

II. How the Message Vector Works 20

III. Environment Effects on Link Availability in Germany 26

IV. Red Force Tactical Objective Priority List 30

V. Red Force C2 Targeting Priority List 34

VI. RF Rule-Based Decisions 38

VII. BF Response to Rule Based Decisions 39

VIII. Table of Automated Systems Data Elements 45

IX. CCMSR Needlines: Tac CP to Other Users 46

X. Service Available to Subscribers 51

XI. Determination of Erlang B Values 55

XII. Determination of Erlang C Values 57

XIII. Recursive Equations 63

XIV. Numerical Example 64

XV. Example Flash Override Delay Times 66

XVI. Relative Entity Utility Value 73

XVII. Static Value Determination Using MADMAN 74

XVIII. SCP or Contingency Decision Alternative Example 87

XIX. Multi Attribute Decision Making Evaluation Example 88

XX. Multi Attribute Decision Alternative Example . . . 89

XXI. Alternative Modes Selected 91

XXII. Minimum Spanning Tree Network Example 93

XXIII. Example 95

XXIV. Multi Attribute Decision Making Evaluation Example 113

XXV. MADMAN Evaluation 114

LIST OF FIGURES

2.1 Communications Module Flow Diagram 21

2.2 Communications Module Flow Diagram (continued) 22

3.1 BF Common User Communications Network 32

3.2 Outline of Red Force Interdiction Module 35

3.3 REC Planning Cycle 36

3.4 RF ECM Interdiction Zones 41

3.5 Tactical Command Post Layout 43

3.6 Type Service Facilities 51

3.7 Network Congestion Algorithm 52

3.8 Priority vs. Non-Priority Queues 58

3.9 Decomposition of Arrivals 61

3.10 Tandem Queue 65

4.1 ASAC to CORPS TOC Needline Routing 70

4.2 Value Degradation Over Time 71

4.3 Static Value Example 75

4.4 Message Scenario 76

4.5 Hourly Depiction of Link Value Versus Time . . . 78

5.1 Tactical Communications Decision making 82

5.2 Multi Attribute Decision Making 84

5.3 Minimum Spanning Tree Example 92

A.1 Resolution Level One 99

A.2 Resolution Level One (continued) 100

A.3 Resolution Level Two 101

A.4 Resolution Level Two (continued) 102

A.5 Resolution Level Three 103

A.6 Resolution Level Three (continued) 104

A.7 Minimum Spanning Tree Program 105

C.1 MADMAN 115
C.2 MADMAN 116
C.3 MADMAN 117
C.4 MADMAN 118
C.5 MADMAN 119
D.1 INTACS and CCMSR Command Structure 120
D.2 INTACS and CCMSR Task Organization 121
D.3 TO&E Units in COMSR Database Theater 122
D.4 TO&E Units in COMSR Database Corps 123
D.5 COMSR Bubble Output 124
D.6 Current COMSR Data Elements 125

I. MOTIVATION FOR HAVING A COMMUNICATIONS MODULE

A. PURPOSE

The purpose of this thesis is to develop the Blue Force (BF) tactical communications network modelling methodology, and where possible present algorithms for use in the Air-Land Interdiction Model (ALIM) being created at the Naval Postgraduate School. The algorithms, hereafter called the Communications Module (CM), facilitate the passage of information between the combat functional area modules being played in ALIM. This thesis has several objectives:

- The development of communications modelling methodology appropriate for supporting the sparsely populated, Echelons Above Division (EAD) area. Several of the prominent communication subscribers in this area are involved in the interdiction battle, and the overall command and control of the Air-Land Battle force.
- Realistic development of the communications network available to Blue forces, and the examination of that network under a variety of degradations expected on the battlefield.
- The development of a credible value system which provides the basis for communications decision making and resource allocation.
- The analysis of decisions that directly impact upon the BF ability to communicate. The Decision Makers, Blue and Red, are analyzed for type decision made, echelons at which decisions are made, when decisions are made, and where possible the value thresholds that trigger alternate decisions.

- The development of automated, closed loop algorithms which can simulate the above decision making.

The ultimate purpose of the Communications Module is to perform research on the conduct and results of the Air-Land interdiction battle. Once completed, the module will be helpful in answering the following questions, however, actual answers to these questions are well beyond the scope and intent of this thesis.

- What factors insure availability of communications systems in a high intensity conflict?
- What are the weak links in a communications plan?
- Can the communications effectively support the interdicters in a timely manner?
- What communications architecture works best to achieve Blue Force (BF) Interdictor goals?
- How sensitive is BF mission accomplishment to communications availability fluctuations?

B. FITTING INTO THE AIRLAND RESEARCH MODEL

Advanced technologies have had a monumental impact upon the lethal capabilities of the U.S. Army. New collection and fusion capabilities within the Intelligence community enhance target acquisition; increased ranges and accuracy of LANCE and PERSHING ground to ground missiles enhance target destruction; vastly improved air defense missiles and target servicing help insure the survivability of Command, Control, Communication, Intelligence (C3I), and logistics. A potential Achilles' heel, the common thread weaving each system to its controller and each controller to his commander, is communications. Every bit of information that passes between two points passes through some form of communications medium. Can we afford to assume that these communications will be available when most needed? Most previous modelling

efforts have either assumed total communications availability or made aggregate reductions in efficiency for some arbitrary value of reduced communications availability. The ALIM will not ignore the critical communications assets because the model's design is a closed architecture which simulates pertinent combat and combat support functional areas supporting the Blue interdiction effort.

C. SCOPE

The scope of this thesis will be limited to the geographical area occupied by the BF Corps from the division rear boundaries through the Corps Communication Zone (COMMZ). Some Theater level units such as the PERSHING Missile Brigade and appropriate C3I facilities which have a direct impact upon the Corps interdiction effort are discussed. Army communications is in the midst of a revolutionary change from tubes to microchip technology, and an equally revolutionary doctrinal change. The communications systems architectures discussed are those being deployed today and in the fully funded, foreseeable future according to the Army of Excellence Doctrine and the Integrated Tactical Communications System (INTACS) at EAD.

II. OVERALL COMMUNICATIONS MODULE CONCEPT

A. INTRODUCTION

The dictionary defines transparent as a property of an object that allows it to transmit light energy unimpeded through its mass [Ref. 1]. The goal of every communicator is that his communications system be transparent to the user. This means that information passing is accomplished in real time and with no loss of content. Obviously, with the restrictions placed upon modern battlefield communications means, transparency is wishful thinking. Near transparency, however, may be possible with the electromagnetic communications systems available within the Army.

Simply stated, the Communications Module (CM) supporting ALIM can be thought of as a black box; it receives information from one user and delivers that information to the destination user after a certain period of time or delay. This delay is the cost of being only near transparent. The CM is concerned not with the content value of that piece of information to either the originator or the receiver, but with how transparent, fast and efficient, the user wants the communication to be. As is readily apparent, the asymptotic approach towards transparency has the deleterious effect of pushing cost to infinity. Technological advances have reduced but cannot eliminate these limitations.

B. CONCEPT

Communications degradation is defined as the reduced ability of a communications system to accomplish its intended mission. In this module, degradation refers to the reduced operational availability of a system that is being

employed in its combat enhancing mission. The research model will have the option of playing communications degradation at three levels of resolution. To the realist it would seem that communications should be played all the time. To the operations analyst, communications should be played, but only after the architecture or processes of the combat functional areas have been optimized. With this optimized product it would then be reasonable to test the combat modules with communications play, thereby isolating shortcomings to the communications systems supporting the functional combat area. All communications systems supporting a particular functional combat subscriber are refered to as that subscriber's Communication Interconnectivity Space.

Level I Resolution assumes 100% availability of communications and real time transfer of information. All database traffic including BF traffic is loaded into the network architecture. The output of circuit traffic loads can be aggregated by link, node, or arena. This method will have the effect of graphically isolating network links and nodes that are choke points as a result of communication architecture planning. This method's results are not confounded by environmental degradation, friendly net congestion, or enemy degradation. This method also shows the parts of the network that have the high value distributions of transiting traffic.

Level II is predicated on the idea of random degradation of links and random delay times for those degraded links. These assumptions have the effect of "shaking down" all links and nodes of the network including those links and nodes that are not considered as priority targets in Soviet objectives. Level II allows the model to be played without having to utilize the Environmental Degradation, Friendly Net Congestion, or Red Force Degradation Submodules. This method is higher resolution because it delves more deeply

into the effects of randomly degrading links or nodes and how the communications planners and commanders at all echelons of communications deal with this reduced ability to pass information. The "dealing" is decided in the Reroute submodule, the rerouting of information around non-operational areas, and the Reconstitution submodule which allocates resources to rectify the trouble in the non-operational areas. This creates a more realistic set of operational circumstances and therefore more reasonable delay times.

Level III plays environmental degradation, friendly net congestion, and most probable enemy degradation efforts. This level also allows the analysis of message flow with or without precedence levels and preempt capability. By analyzing the message vectors with their built in audit trails, we may determine the communication network's strengths and weaknesses. This method will closely emulate the communications obstacles that face V Corps in the Fulda Bowl area. (see Table I)

The Level III Resolution consists of four rule-based decision submodules, three chance or Monte Carlo (MC) decisions based upon probabilities, five processes with imbedded decision submodules, and three databases. Expert player experience is a necessity in developing these rules. The research task focuses on the identification of the network attributes, data elements, and network algorithms required to model the diversity of systems and environmental features of the Air-Land battle.

Detailed analysis of the Communications Module centers on the traffic load presented to the network by the BF interdiction related functional areas. This traffic, which makes up a very small portion of the total communications load, is referred to as the marginal traffic. Analysis of the marginal traffic saves on the enormous memory required

TABLE I

Communication Submodules

Decisions	Processes	Database	Monte Carlo
User to User	Static Link Valuation	Network	*Availability
*Degradation	*Non-op Link Valuation	Communications Support Requirements	*Circuit Connect
*Reconstitution	Cr Link Valuation	MTO&E	*Acquisition Destruction
*Reroute	*Net Congestion		
	Busy Link Valuation		

* Not included in Level One

to simulate all the message traffic that would flow through every circuit and link. The module translates the communications database into flow rates per busy hour emanating from a particular user across an arc or link. Using Stochastics, specifically Telephone Traffic Theory, the CM can deal with the database by storing only the flow rates. The marginal traffic is explicitly simulated and critical information is maintained by means of the message vector.

The message vector is the thread of continuity running between all decisions, processes, and databases. Once the decision has been made to play the CM, then a message vector must be initiated by the originating module. The originator (O) has a requirement to pass information to the receiver (R). In a real world situation, the originator often unconsciously determines how urgent the information is. In Table II the decision would lead him to select a transmission medium which is both available to himself and the distant

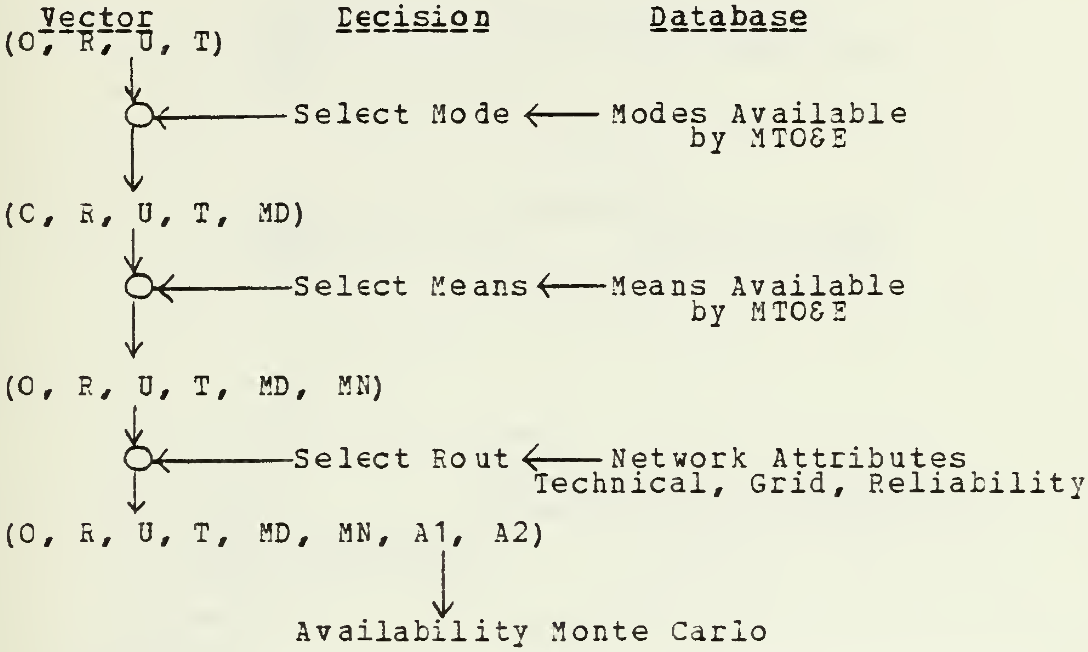
end, and one which will satisfy the urgency (U) of the information. As it flows through the CM, the message vector accumulates the pertinent information parameters which will eventually provide a detailed audit trail for each message and when aggregated it will be the fundamental basis for determining asset values for links, nodes, and arena. The time clock starts when the message is initiated. At the end of the CM, the message vector outputs only the originator, receiver, content, classification, and elapsed time (T). Other parameters that are essential to the CM are the mode (MD), means (MN), availabilities of primary routes (A1), and availabilities of secondary routes (A2). Some parameters may be vectors in themselves. Such vector parameters are the modes, means, and availabilities for multi link routes.

Figures 2.1 and 2.2 trace the flow of information through the CM at Level III Resolution. Essentially the User to User submodule, as alluded to previously, selects the routing between originator and receiver based upon the Network Database. The Network Database contains records on the actual hardware network that is initially operating, specific unit communications equipment (modes and means), and other technical data concerning equipment capacity, survivability, speed of transmission, etc. . In Figure 2.2, the ability of the selected route to pass information is tested probabilistically based upon route availability.

The initial availability of the route is drawn from technical calculations and historical data. Availability can also be affected by equipment outages and enemy electronic countermeasure activities . The Communications Degradation submodule evaluates enemy intentions and capabilities versus BF counter-capabilities and produces a "reduced availability" link list. Interconnected with the Degradation submodule is the Reconstitution submodule. This submodule examines "below availability standards" links for their

TABLE II

How the Message Vector Works



static and potential value if the link was being used, and establishes a priority for repair of damages. In other words, based upon the link's total value, the submodule allocates resources to repair damage and forecasts the time until the link is back up to acceptable availability standards.

If the probability test, commonly referred to as a Monte Carlo technique, replies negatively, then the message vector goes to the Reroute submodule where another route is selected for Monte Carlo; time accumulates. The information on which link produced a non availability is forwarded to the Valuation of Non-operational Link Process.

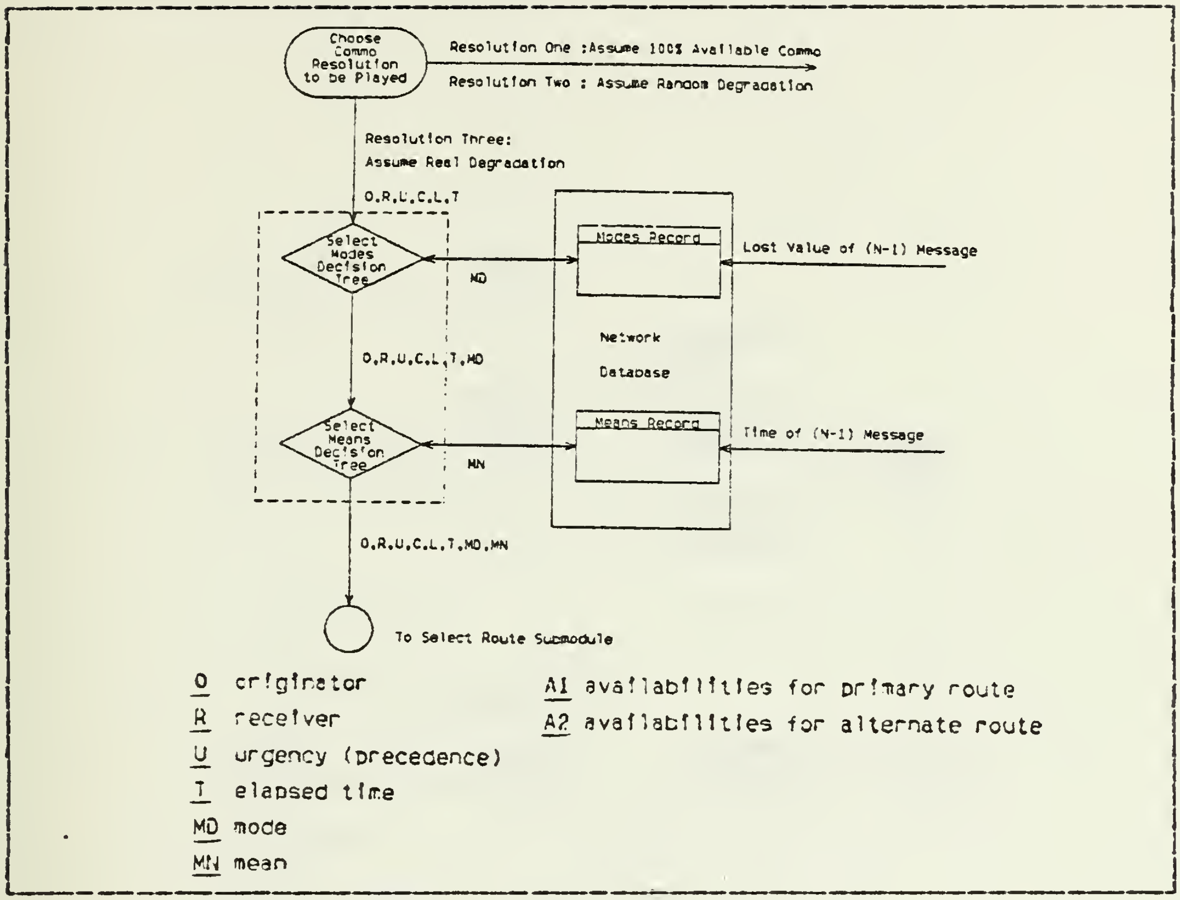

Choose Commo Resolution to be Played
Resolution One :Assume 100% Available Commo
Resolution Two : Assume Random Degradation
Resolution Three: Assume Real Degradation
O,R,U,C,L,T
Select Modes Decision Tree
MD
Modes Record
Lost Value of (N-1) Message
Network Database
O,R,U,C,L,T,MD
Select Means Decision Tree
MN
Means Record
Time of (N-1) Message
O,R,U,C,L,T,MD,MN
To Select Route Submodule
O originator
R receiver
U urgency (precedence)
T elapsed time
MD mode
MN mean
A1 availabilities for primary route
A2 availabilities for alternate route

Figure 2.1 Communications Module Flow Diagram

Somewhat less damaging, but just as aggravating to the user, is the busy signal symbolic of net congestion. The user could get a busy signal either from an overloaded communications link or from an overloaded distant end user. In either case, the originator must hang up and dial again (return to the USER to User submodule) or select an alternative means of communicating. The decision here is based upon the probability of getting a busy signal and is called the Circuit Connect Monte Carlo (CCMC).

If the user connects to his distant end, the message transit clock is stopped. The message vector goes to the Valuation of Operational Link process, and finally the message reaches the distant end.

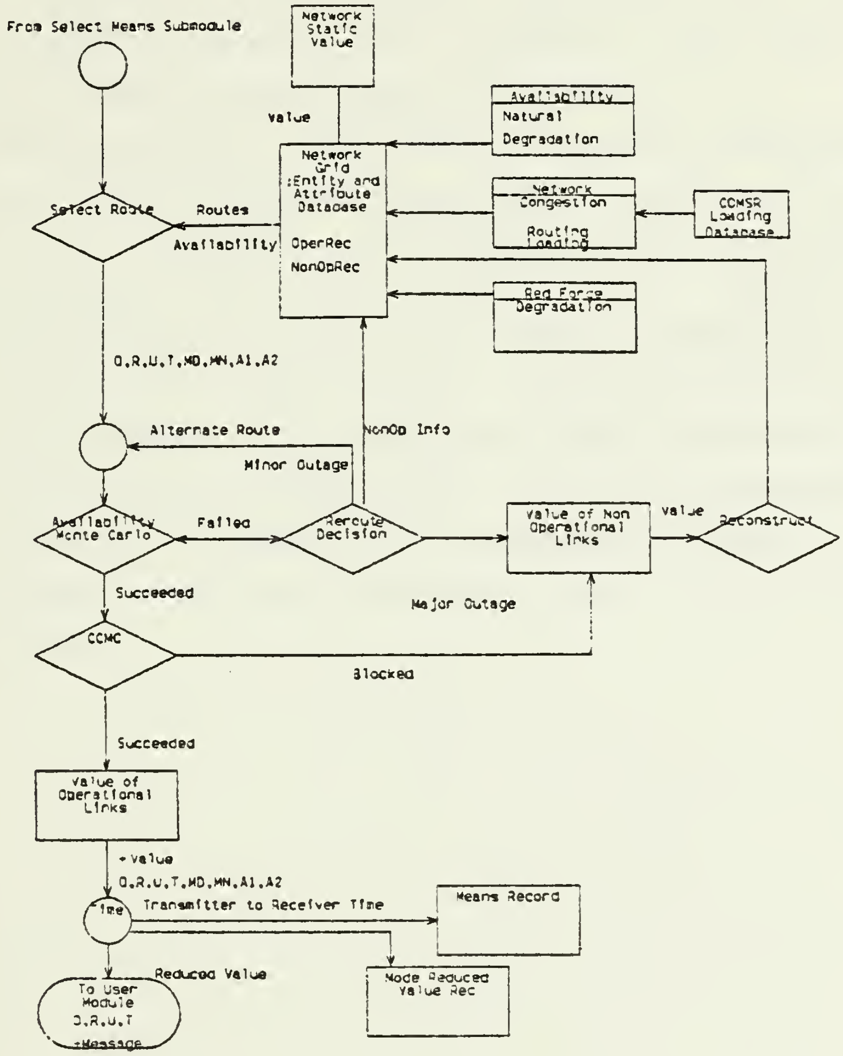


Figure 2.2 Communications Module Flow Diagram (continued)

The value determining processes are key. They keep track of value information which in the future will allow us to answer our research questions. The Valuation processes evaluate the communications assets worth at various levels of aggregation. Audit trails and information critical to resolving current communication problems and plans for future optimal systems to support the Blue Force Interdiction (BFI) effort can be analyzed.

To review briefly, this thesis develops modelling methodology and where possible presents a candidate algorithm. Submodules of the CM are at various levels of maturation. Some submodules are very mature and in these cases a detailed algorithm is presented. Other submodules are far beyond the scope of this thesis. Areas that are of concern to these submodules are highlighted and discussed in lesser detail with a sketchy algorithm. Under no circumstances is there an attempt to answer the research questions. The goal is to provide a vehicle which may shed light into these question areas.

III. COMMUNICATION DEGRADATION SUBMODULE

A. INTRODUCTION

A transparent communications system is one which passes information from one subscriber to another in real time with no loss of content. Real time transfer is possible in a laboratory with controlled message input and output. In the real world of the U.S. V Corps, Federal Republic of Germany, transparency is a myth. Blue communications in the region face three forms of degradation. These degradations would easily thwart communications support for the interdiction forces if not taken into consideration in communications planning. Definitions of functional forms of degradation and how they effect communications are briefly discussed below.

1. Environmental Degradation

Environmental Degradation consists of two categories, natural and hardware. This form of degradation should not be confused with the the human induced Red and Blue Force Degradation discussed in later sections.

Natural Degradation is the sum total of the effects of such occurrences as atmospheric turbulence (ionization and stormy weather), terrain cover (trees and buildings), background electronic interference (car ignition systems, power lines, commercial TV and radio stations), and poor grounding effects (soil grades and absorption rates).

Hardware Degradation results from a combination of weather extremes, both hot and cold, and humidity levels which not only effect the operating tolerance levels of electronic equipment but also effects their serviceable

lifetimes. This form of degradation also takes into consideration the normal lifetime of a piece of equipment and its mean time between failure.

Environmental Degradation may be simulated in several ways. The simulation results, however, would be highly suspect due to the vast number of assumptions that would be necessary. Reliability Theory can be systematically applied to determine the Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) of a link. Dichotomies exist between the assumption of independent and identically distributed Exponential random failures and the data that is available from operational experience. MTBF and MTTR data is calculated by component in a laboratory. When MTBF and MTTR are computed, we are actually finding the achieved availability. This method assumes no administrative, logistic, or preventive maintenance downtime. In an operational field environment, however, a component failure within a communication van does not necessarily mean a link outage; in fact, the failure may not have an impact at all.

Operational data is available only on actual link nonavailability time. The nonavailability time may be the result of atmospherics, equipment, mutual interference, operator headspace, power surges or a host of other degrading causes. The actual reason for outage may never be known, and that makes the systematic application of reliability theory difficult at best. Environmental degradation is very difficult to measure if we attempt to look at the multitude of influencing variables individually. However, reams of historical data are available from previous training exercises conducted in the V Corps region over the last 40 years. This data spans all seasons and gives an approximate sum total effect of the environment on link availability. In Table III, for example, we can see that if information is routed over a microwave system that did not

require a relay between the subscribers, then the operational availability would be 95%. Operational Availability is defined as the probability that a system or equipment will operate satisfactorily when called upon in an operational environment.

TABLE III

Environment Effects on Link Availability in Germany

Entity	Attribute	Average Operational Availability
Microwave	No relay	95%
Microwave	One relay	90%
UHF	No relay	90%
UHF	One relay	80%
VHF	No relay	95%
VHF	One relay	90%
S/C Radio	No relay	85%
S/C Radio	One relay	70%
S/C RWI	Wire Integration	80%

Ao= Operational Availability =(MTBM)/(MTBM+MDT)
= (operational hours)/(total hours required)

MTBM
=mean time between maintenance (scheduled or unscheduled)

MDT
=mean maintenance downtime (includes scheduled, unscheduled maintenance, administrative and logistic delay times
[Ref. 4].

It is recommended that using the available mean data for the geographical region is the best estimate. Simply test by Monte Carlo, if nonavailability results, then the actual outage time should be an exponential draw of mean: $(\underline{\lambda})$ = (1-.95) x 24 hours= 1.2 hours for the Microwave System in Table III.

2. Red Force Interdiction

RFI consists of all attempts to either actively or passively interfere with Blue Force transmission of information. Active interference means the use of Electronic Countermeasures such as jamming or destruction by fire. Passive interference means the mutual interference occuring when Red Force (RF) subscribers are attempting to transmit on the same channel as BF users. Nuclear munitions also have a disastrous effect upon the frequency spectrum, but are not intended solely to degrade Blue communications. In fact, these passive degraders often effect Red communication as much or more than Blue, and are considered in Red interdiction planning.

This thesis attempts to define the parameters necessary to determine the impact of various Red interdiction efforts upon Blue communication. It is not an in depth analysis of all facets of Red Radio Electronic Combat (REC). "Most probable" guesses, with credible backup sources, are made about Soviet intentions and capabilities . Soviet electronic interdiction and the resulting Blue degradation are analyzable through the use of Signal Detection and Probability of Hit and Kill Theories. More study and detail will be necessary to develop a detailed algorithm. The area of passive interference is discussed from the nuclear point of view in a somewhat deterministic manner; the problem of mutual Blue/Red interference in the frequency spectrum, although enormous, will not be discussed.

3. Blue Force Net Congestion Degradation

Blue Force Net Congestion Degradation is discernable in two areas, trunk congestion and terminal congestion. These congestions result from the overloading of either trunk or terminal systems with messages at a point in time.

An understanding of the causes of message delay is important because system planning can usually alleviate most congestion. Congestion is currently a resolvable problem facing the communications staff prior to the start of the war. It is extremely difficult to isolate, analyze, and solve once the war has begun.

B. RED FORCE INTERDICTION DEGRADATION

1. Introduction

This section of the thesis is not intended to be a fully developed, mature submodule because the subject matter is highly complex and can be a thesis topic in itself. The section is critical to the credible development of the BF communications availability. Major points of interest are discussed and a sketchy algorithm is presented in lieu of just ignoring a vital player in the Communications Module. Further analysis of this area is mandatory. Inherent in the analysis of RFI are the explicit tasks of:

- Determining the Soviet strategic and tactical priorities relative to the BF communications.
- Analyzing Soviet intentions based upon their scientific approach towards BF communication in a war scenario.
- Discussing both input and output parameters and how they would satisfy the demands of other submodules of the communication module.
- Developing a relatively simple algorithm which considers the pertinent areas of RF interdiction and the BF ability to counter RF interdiction. (Note: actual capabilities are highly classified and should be handled as parametric inputs to submodule. They are not discussed here.)

2. Soviet Strategic and Tactical Priorities

The first task is to determine RF strategic and tactical priorities that relate to BF communications. A noted Scottish scholar on Russian affairs, J.D. Douglas states:

> To the Soviet, Lenin taught that war is the continuation of politics. Capitalism.. . should be eliminated by the revolutionary struggle.. . under the conditions of peaceful co-existence. The Soviet must be prepared for the wars it would like to prevent, particularly, nuclear war. [Ref. 6]

Prevent is the key here. The Soviet Union emphasizes that it must have such overwhelming superiority, that no realistic government would ever challenge their right to survive. To the Soviet, "Prevention" means seizing the initiative and pre-empting in order to disrupt the enemy's surprise attack. Should the world destabilize to the point that the Soviets feel war is necessary to attain their ultimate goal, then war it will be to its victorious end.

In his book, Basic Principles of Operational Art and Tactics, Colonel D. Savkin, a noted Soviet author and Army officer, states that nuclear weapons will be used with suddeness and in mass throughout the BF deployment. The objective is to destroy armored groups, major command posts, junctions of lines of communication, and critical rear area objectives particularly the BF nuclear, air defense, command, control, and communications facilities. [Ref. 5 pp 190 - 191]

Narrowing the scope of this operational strategy to the BF Corps, and using Soviet intonations as found in open literature, the following list (see Table IV) of targeting priorities emerge as sequential events during the early days of the next war. If these targets are not destroyed immediately, the RF will continue to execute the priority

list. Even partial success insures a greatly diminished BF capability to resist for more than a few days.

TABLE IV

Red Force Tactical Objective Priority List

Time Sequence of Execution	Objective	Priority
1	Disrupt C2 of air defense	3
2	Destroy Patriot/Hawk Batteries air-air capability	4
3	Disrupt C2 of nuclear capable units	1
4	Destroy or capture nuclear units	2
5	Neutralize C3I facilities	5
6	Destroy junctions of lines of communications	6
7	Reserves especially armor and artillery	7

The Soviets feel that these tactical objectives within the BF Corps can be attained at least cost by means of a pre-emptory mass nuclear strike followed by deep airborne and armored thrusts into the BF Corps and Division Rear Areas of operation. Their success or failure in attaining these objectives early means winning or losing the war. If successful, then BF political capitulation is expected. [Ref. 6]

3. Soviet Intentions to Interdict BF Communications

The second inherent task is to analyze Soviet intentions, based on their scientific approach, towards BF communications in a combat scenario. The scientific approach to solving military problems is ingrained into the Soviet staff

officer's training very early in his career. This scientific approach, as it applies to our Corps battle, covers the areas of operations research, particularly cybernetics, modelling, and network theory.

a. Operations Research and System Analysis (ORSA)

The Soviets are heavily involved in the use of ORSA techniques such as combat modelling and network theory. Extensive operational and predictive modelling is used to determine reasonable probability estimates of carrying out BF strategy given enemy capability and willpower. Network theory is used to plan information, logistics, and troop unit flow patterns that optimally fulfill operational requirements. Extensive unclassified literature concerning BF communications systems is available to Soviet planners. It is reasonable to believe that the Soviets could model BF communications systems. Using Network theory, they could find critical links and choke points. These critical links, if destroyed, would severely hamper BF capabilities.

In Figure 3.1, the BF Common User Communications Network overlayed on a portion of the EAD Communications Zone is depicted. If Soviet Intelligence is able to find or predict where critical BF control points and units are located then a simple network analysis will tell them where to look for certain "signature" types of communication equipment and where to maximize the effects of interrupting BF communication with commando or air interdiction units.

b. Cybernetics

Fundamental to Soviet strategy is the belief that successful combat operations depend mainly on the flexibility and efficiency of the automated Troop Control System. To expedite the solutions of problems that might be encountered in preparing combat activities, they feel it is

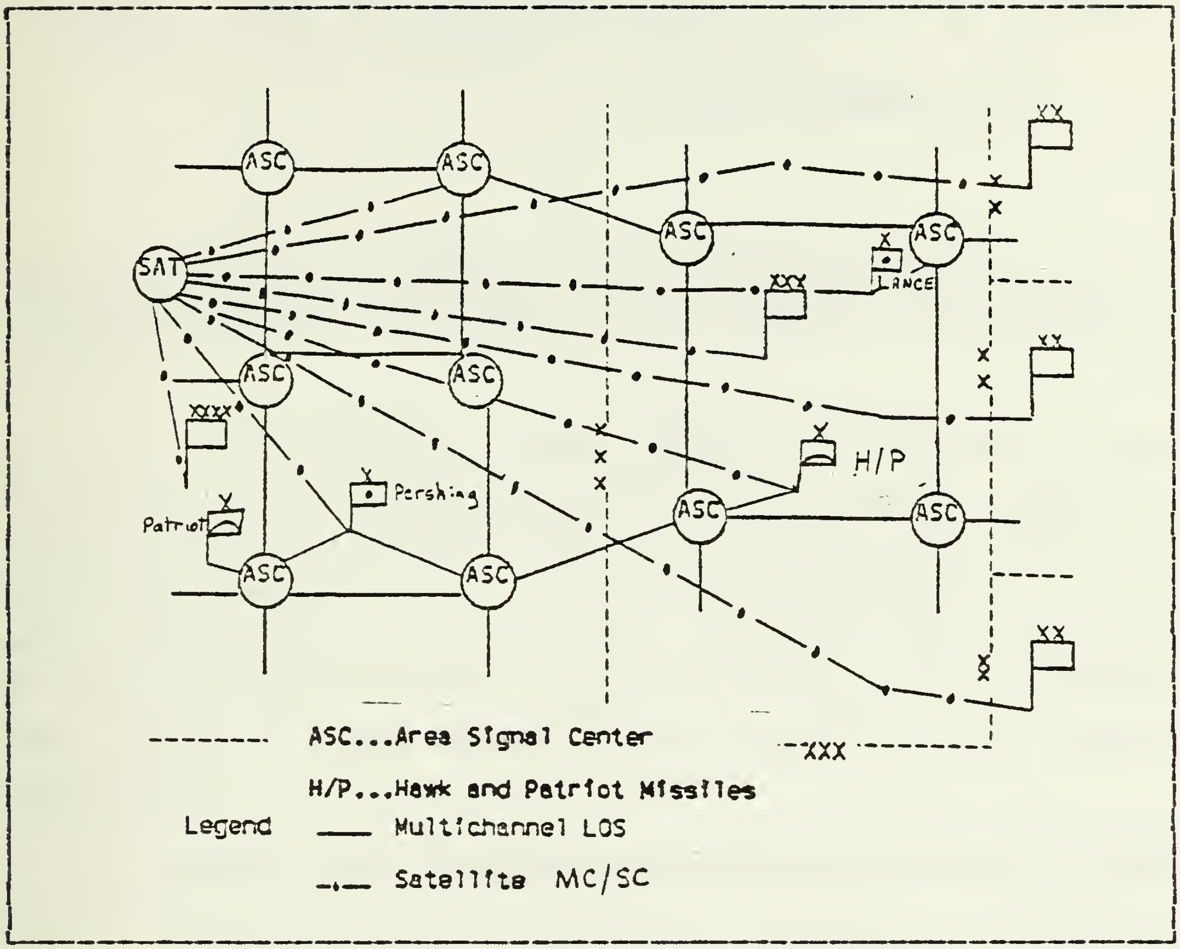


Figure 3.1 BF Common User Communications Network

necessary to formulate computer algorithms. Computers are currently being planned for or used to encode and decode information, to evaluate effectiveness of combat methods, and to solve target allocation problems. They are also used to fuse data necessary for command in decision making, to process data related to logistics and movement, and to make calculations related to combat readiness, specifically correlation of force determination [Ref. 7].

The Soviet considers communications as one of the most valuable and vulnerable portions of automated command and control systems. It General Titov states :

> Communications is the basic means to ensure troop control. Loss of communications is the loss of troop control, and the loss of troop control in battle invariably leads to defeat. [Ref. 3]
>
> Lt. General Titov
> Voyenny Vestnik #7, 1971

> REC Doctrine establishes a requirement to jam at critical time Army - Air Force C2 and weapon system communications when they cannot be destroyed by fire power. [Ref. 3]

The critical command and control assets within the BF Corps that the Soviets deem their highest priorities and the Soviet attack time sequence are listed in Table V . Attack sequence is for RF air interdiction purposes. It is safe to assume that Unconventional Warfare units already in BF rear areas would attack all areas simultaneous to create mass confusion and detract from effective air defense capabilities.

4. Details of a Potential RF Interdiction Module (RFIM)

Design of this module is obviously a thesis in itself, and will require a much more detailed excursion into the Soviet mindset for planning and executing Intelligence gathering efforts than is presented here. This subsection attempts to pinpoint the crucial "who, what, where, and when" related to RF decisions that affect Blue communications[1].

The outlined RFIM, seen in Figure 3.2, examines the RF interdiction priorities and capabilities and selectively reduces the availability of certain BF links. The reduced availability links are parametrically input into the

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[1] For more detailed information about intelligence collection and fusion see Gandy, Intelligence Collection Management ,Thesis, Naval Postgraduate School, Monterey, California, June, 1984.

TABLE V

Red Force C2 Targeting Priority List

Attack Sequence	Targeting List	Priority
1	Automated Air Defense C2 system (TSQ-73) & Communications	2
2	Automated Fire Planning/ Resource allocation for nuclear capable units & communication ;TACFIRE	1
3	Semi-automated intelligence collection and fusion by ASAS All Source Analysis System	3
4	Logistic systems supporting nuclear units and movement of special ammunition & communications, and reserves.	4

[Ref. 3]

Communication Network database where updating of link status takes place. The RFIM list also goes to the Reconstitution Submodule and to the Non-operational Valuation Process.

The Soviets intend to inflict grievous destruction upon C3 systems using Unconventional Warfare and Radio Electronic Combat prior to and during all phases of the next war. The Soviets define these terms as follows:

a. Unconventional Warfare (UW)

The UW forces conduct reconnaissance, espionage, sabotage, assassination, and interdiction of lines of communications. UW is designed to weaken military capabilities of target country and support follow on conventional military operations. The Soviets have several hundred thousand people directly involved in this effort. [Ref. 2]

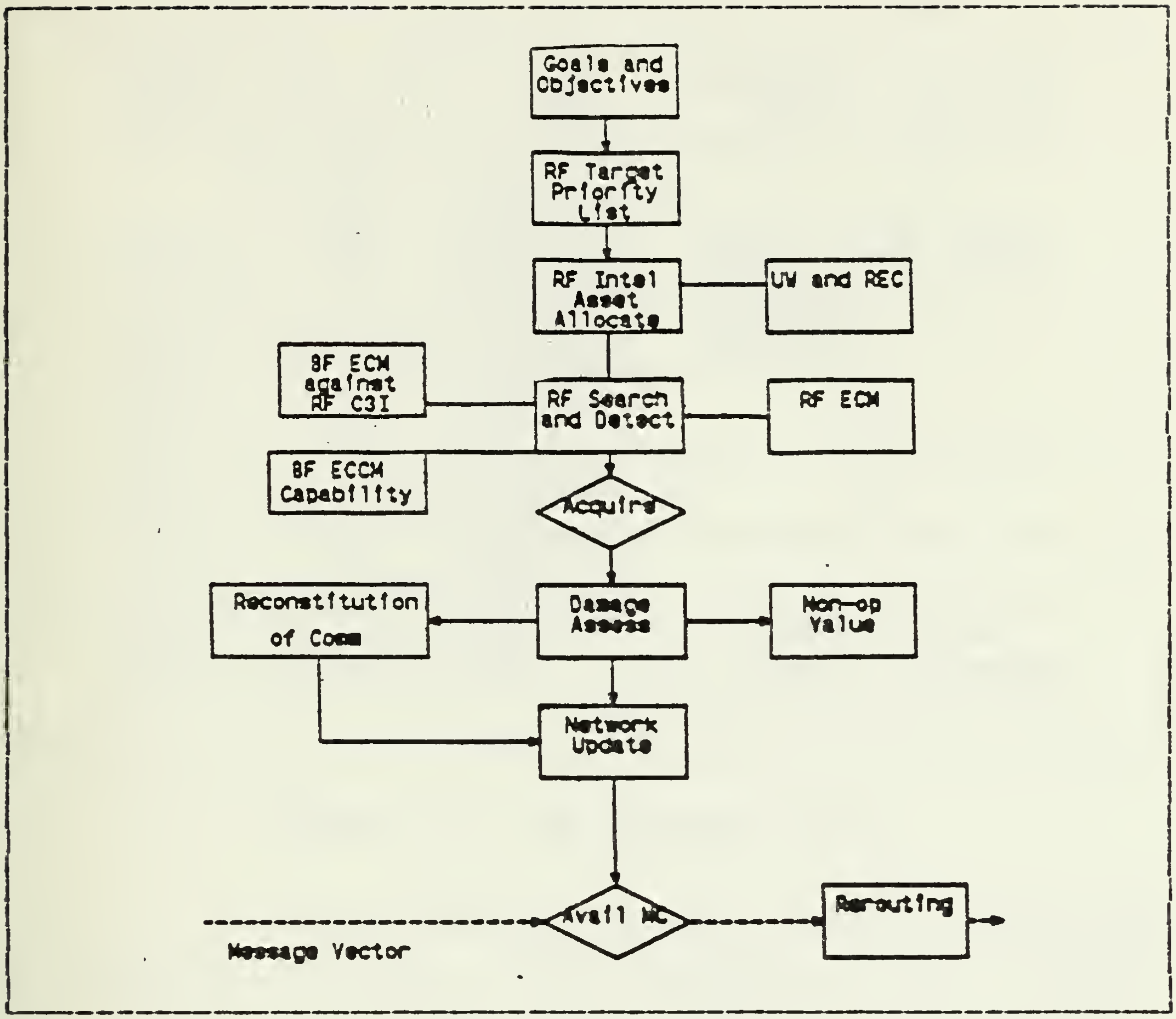
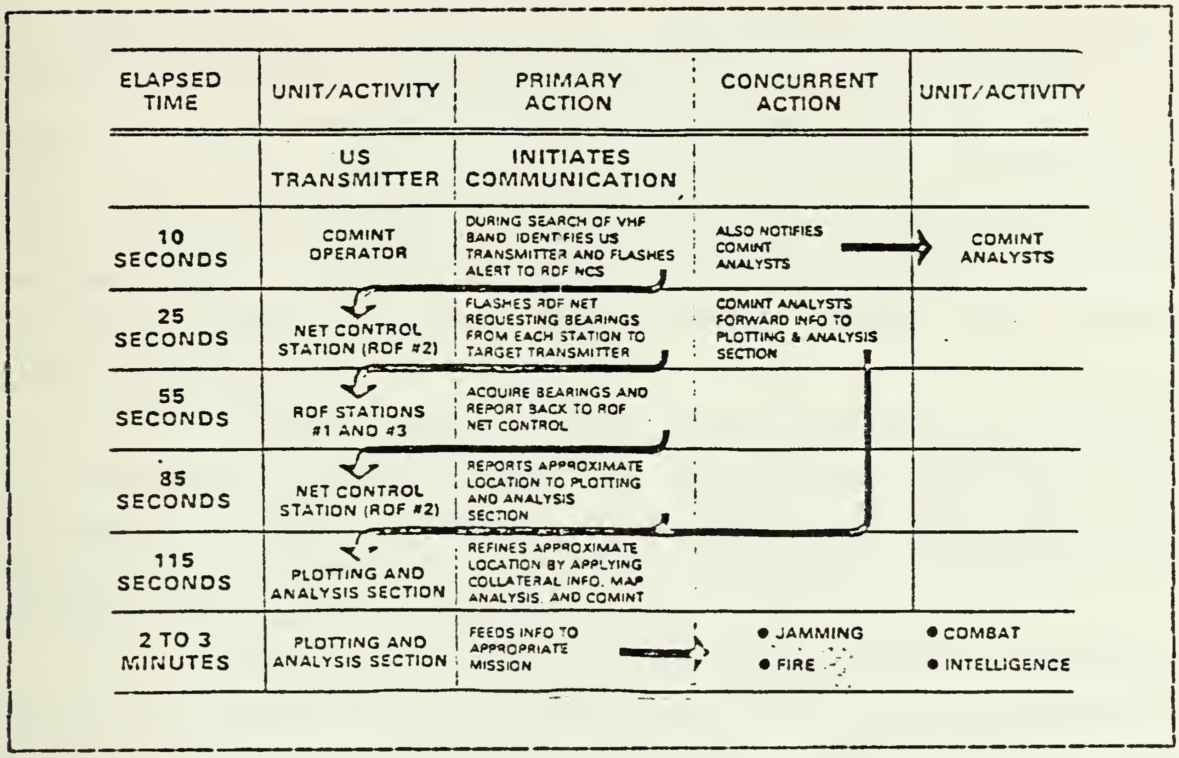


Figure 3.2 Outline of Red Force Interdiction Module

b. Radio Electronic Combat (REC)

The purpose of REC is to limit, delay, or nullify the enemy's use of his command and control systems, while protecting Soviet systems by electronic counter-countermeasures. The aim of REC is to disrupt the enemy's critical time phasing to the extent that perishable information (on which decisions and orders are based) is obsolete. Figure 3.3 gives a RF planning cycle for REC. [Ref. 3]



ELAPSED TIME	UNIT/ACTIVITY	PRIMARY ACTION	CONCURRENT ACTION	UNIT/ACTIVITY
	US TRANSMITTER	INITIATES COMMUNICATION		
10 SECONDS	COMINT OPERATOR	DURING SEARCH OF VHF BAND IDENTIFIES US TRANSMITTER AND FLASHES ALERT TO RDF NCS	ALSO NOTIFIES COMINT ANALYSTS	COMINT ANALYSTS
25 SECONDS	NET CONTROL STATION (RDF #2)	FLASHES RDF NET REQUESTING BEARINGS FROM EACH STATION TO TARGET TRANSMITTER	COMINT ANALYSTS FORWARD INFO TO PLOTTING & ANALYSIS SECTION	
55 SECONDS	RDF STATIONS #1 AND #3	ACQUIRE BEARINGS AND REPORT BACK TO RDF NET CONTROL		
85 SECONDS	NET CONTROL STATION (RDF #2)	REPORTS APPROXIMATE LOCATION TO PLOTTING AND ANALYSIS SECTION		
115 SECONDS	PLOTTING AND ANALYSIS SECTION	REFINES APPROXIMATE LOCATION BY APPLYING COLLATERAL INFO, MAP ANALYSIS, AND COMINT		
2 TO 3 MINUTES	PLOTTING AND ANALYSIS SECTION	FEEDS INFO TO APPROPRIATE MISSION	● JAMMING ● FIRE	● COMBAT ● INTELLIGENCE

Figure 3.3 REC Planning Cycle

A typical Radio Electronic Combat scenario may go something like this. A must assumption is that RF goals, objectives, and priorities are satisfied by attacking the BF air defense (AD) C3 facilities at Corps Level. The Soviet planners would set out to develop a plan to allocate intelligence gathering assets and then destructive assets to degrade the Hawk/Patriot missile systems' C3. Map reconnaissance, human intelligence, electronic intelligence and signal intelligence are used to establish location of AD targets. Communications emitters are more difficult to find than radars. If radar is found, then communication emitters must be nearby. AD communication emitters are easy to interdict if a location and approximate frequency is known.

If and when a target is found, it is jammed, deceived, or destroyed. BF communications in the AD arena

are jam resistant. They have low susceptibility to ground direction finding. They are secure to prevent deception. They are highly redundant both in equipment and in transmission path to prevent catastrophic loss of information. Since standoff jamming and deception efforts would probably be less than successful, the RF planners devise a plan to attack AD with unconventional warfare teams and ground attack aircraft.

At a planned point in time (usually at the start of hostilities) unconventional warfare teams, already behind BF lines, attempt to jam AD "Air Battle Control" nets. EW equipped aircraft attempt to blind the radars. Ground attack aircraft then attack isolated AD targets.

BF communications controllers assess communications degradation and allocate backup nets and equipment to overcome degradation or non-available links both in the real world and in the model.

If we examine each process within the degradation scenario, we can see many explicit and implicit decisions that must be modelled on both sides. Table VI lists a few of the decisions made over the course of planning and executing the war from the Soviet point of view and then the countering decisions from the BF point of view.

TABLE VI

RF Rule-Based Decisions

Decision	Level of Decision	Rule	Time
Start hostilities Goals & Objectives	Politburo	Must insure Dialectic success	2
Plan & execute hostilities Target priority List	General Staff	Maximize destruction on the enemy in shortest period of time to insure quick capitulation	1
Plan & Execute Strategic UW Civil	KGB	Maximize Civil Unrest in Enemy Heartland	1
Plan & execute Strategic UW Military	GRU	Minimize Enemy Operational Readiness & Effectiveness	1,2
Plan & execute Operational UW	Front	Minimize enemy ability to defend & move reserves	2
Plan & execute Tactical UW	Division	Minimize enemy ability to defend & counterattack	2
Plan & execute Electronic Intercept & Direction Finding	REC Unit	Maximize collection of accurate and timely info from ground and airborne collectors	4
Listen then Jam or destroy voice nets	REC Unit	If high priority of secure net jam then destroy	4
Listen then jam or destroy data nets	REC Unit	If unsecure then listen, deceive, jam, then destroy	4
Employ large deception plan	Army or higher	Maximize confusion	1,2,3

Time: 1. Before hostilities 2. Beginning of hostilities 3. Ongoing 4. Follow Attacking Units 5. As Required

TABLE VII

BF Response to Rule Based Decisions

Decision	Level of Decision	Rule	Time
Plan & execute ECCM techniques	Operator/Super	Minimize ECM effects	5
Defend Site	Next higher OIC	Minimize Communications lost	5
Change Frequency	Net Control	Minimize Degradation	5
Redeploy from site	Next higher OIC	Minimize Communications lost	5
Attack RF jammers	Division	Minimize Degradation	5
Reconstitute	Next higher authority or Sig Brigade	Minimize Degradation	5
Alert Supported Units of inpending air attack	Site OIC	Minimize Damage to supported units	5
Alert Air Force AD coordinator	Site OIC	Minimize Damage to supported units; Minimize losses to AD units	5

Time: 1.Before hostilities 2.Beginning of hostilities 3.Ongoing 4.Follow Attacking Units 5.As Required

Figure 3.4 depicts the BF Corps Area under UW and REC attack. The shaded zones near the line of contact (FEBA) depict the best military judgement probabilities of radio-electronic intercept, direction finding (DF), and jamming usage. The softer underbelly areas in the Division and Corps rear areas depict the employment of GRU, SPEZNETS, and airborne commandoes whose specific mission is to maximize disruption in the rear area, seize or destroy nuclear ammo and delivery systems, destroy air defense systems and associated command, control, and communications facilities. The ability to penetrate forward defenses is not an issue, however, assuming penetration, the probability of mission success is an issue. Mission success depends upon commando search and detection capability and the ability of the BF electronic counter-counter measures to mask EM emissions and exploit anti-jam techniques.

c. The Nuclear Question

A mass nuclear attack upon key installations in the Corps and Division Rear Areas would temporarily blind all but the most hardened of communications systems as a result of the Electro-Magnetic Pulse (EMP). The ability of communication links to be restored depends upon classified technical parameters of each system, the distance from ground zero, and the atmospheric conditions. (The characteristics can be input as parameters and obtained by table lookup for the module.) A nuclear air burst at 50 KM height can knock out communications in an entire theater for a period of time. It is pointed out that this would effect both BF and RF communications and would most likely occur at the beginning of the war. This tactic maximizes the effectiveness of the side that has done the best planning and needs nothing more than non-electronic signals to execute plans. In the module, nuclear attack parameters can be

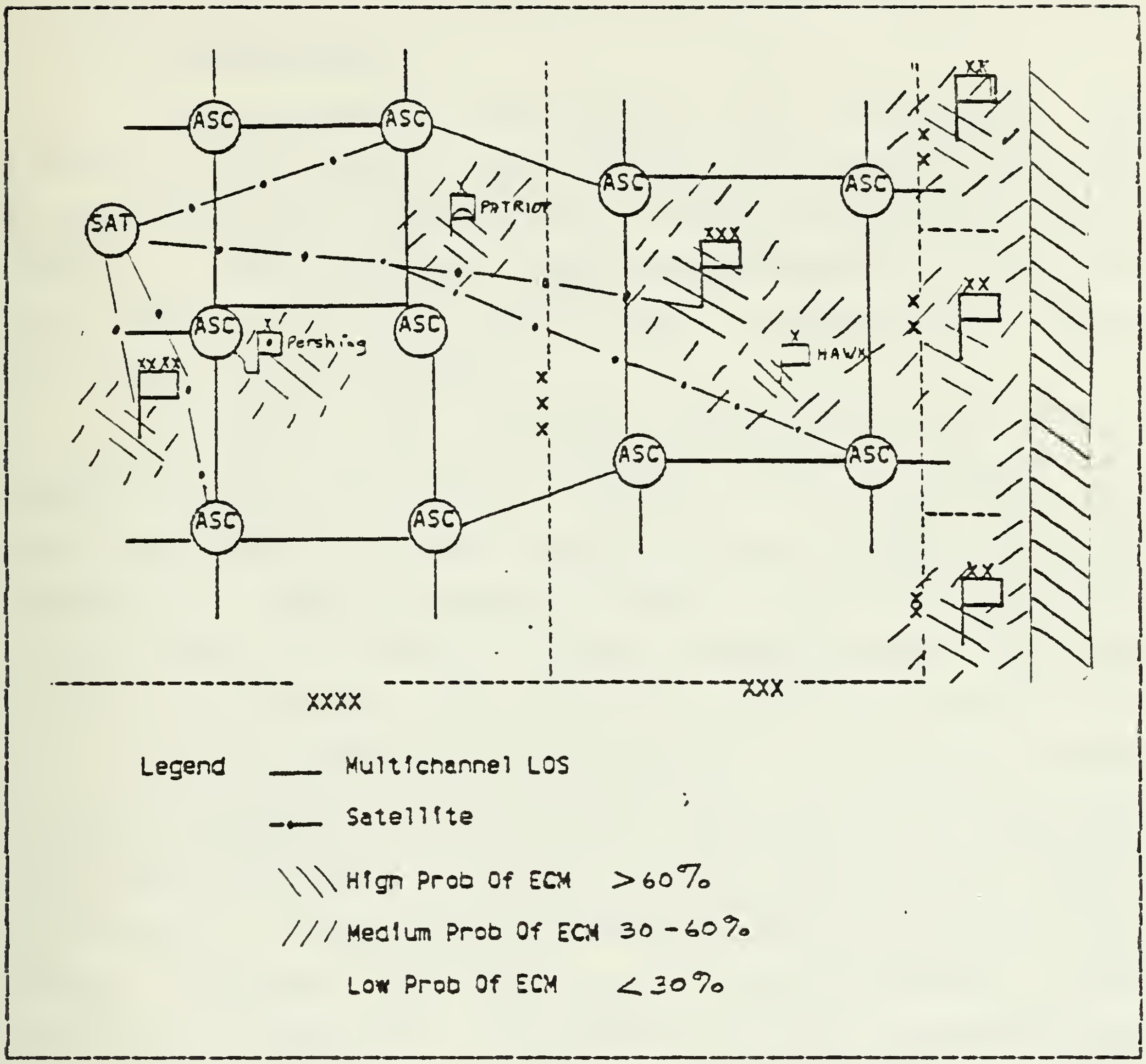


Figure 3.4 RF ECM Interdiction Zones

handled the same as any other attack except that the probability of reduced availability for most links would be near one. After a period of time, links regain availability levels dependent upon their distance from the burst. Quickly following this mass strike are armored assaults and airborne insertions. After this, the most likely interdiction are by ECM trained commandoes and manned or unmanned jammers remotely emplaced in the rear area.

C. BLUE FORCE NETWORK CONGESTION AND DEGRADATION

1. Introduction

The purpose of this section is to determine the probability of messages being delayed[2] and the Expected Time of Delay for Blue communications traffic and network architecture. This submodule has been developed in detail and has reached the "stand alone" level of maturity as far as the algorithm is concerned.

Throughout this section, analysis will be made of the multichannel systems and terminal equipment supporting a Tactical Command Post (see Figure 3.5) to determine the cause and effects of trunk congestion and terminal equipment congestion. Trunk congestion refers to the overloading of circuits that flow over the links between nodes. The busy signal one receives after dialing only the area code or prefix of a telephone number is called a trunk busy signal and is an example of trunk congestion. On the other hand, terminal congestion is caused by having too few telephone instruments available to meet a given trunk demand and is indicated by a busy signal received after dialing all the numbers including the last four. The hardware layout depicted in Figure 3.5 is similar for all communications architecture variations. Analogous situations occur in the use of single channel net radios. The busy signal here is not a nagging phone busy tone, but the operator is keenly aware that someone is transmitting; his net is busy because his radio receiver is "seized" by the current user and he cannot transmit effectively. He must wait for his frequency to clear to transmit, just as the telephone subscriber must wait for a circuit to become free.

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[2] A fairly good measure of effectiveness of a service is provided by the probability that an arriving customer will not be given immediate service. This probability is called the loss probability or the delay probability.

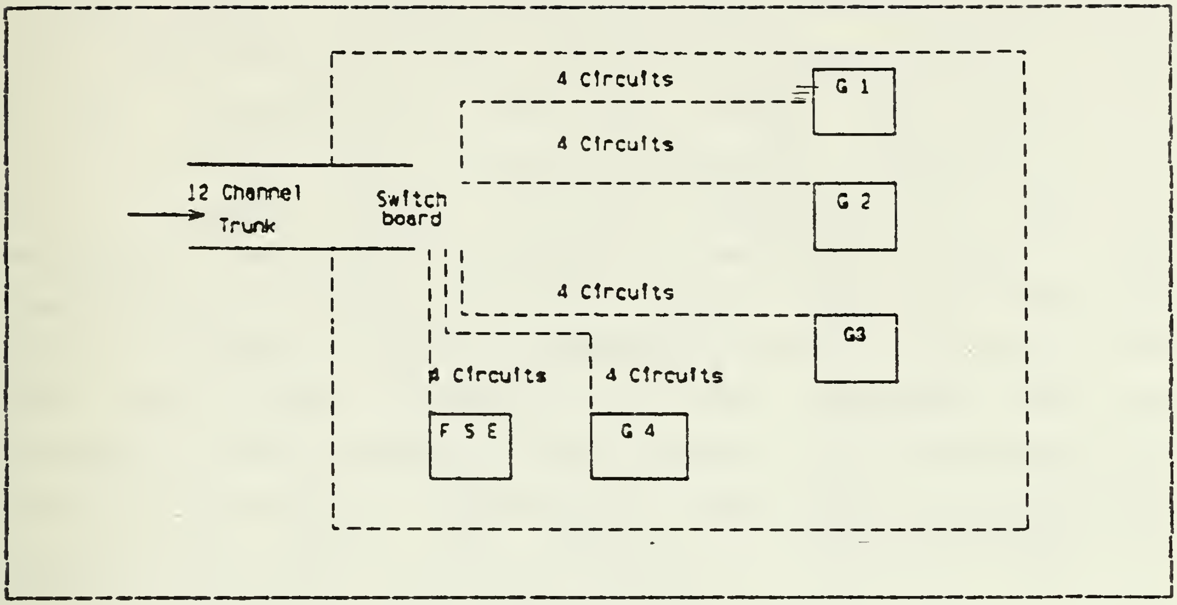

Figure 3.5 Tactical Command Post Layout

2. Message Traffic Database

This portion of the module (see Figure 2.1) requires a communications requirements database to be loaded into the network architecture to provide the "all other" traffic which the Blue Interdiction Force communications must compete with for electronic paths. The only database currently available is the Communications Support Requirements (COMSR) Database.

The COMSR Database is a file of communications needlines owned by the US Army Signal School, Ft. Gordon, Georgia, and stored at the Data Processing Field Office, Fort Leavenworth, Kansas. The database was originally built using the Delphi techniques at the TRADOC Branch Schools, but has fallen into a state of disrepair and disfavor because it has not been updated and revalidated in recent years. However, COMSR possesses the only past validated communications needlines and data elements in the Army. Near term requirements call for revamping and updating of the

original COMSR, probably using the data elements and procedures developed during the Battlefield Communications Review on Data Distribution.[3] (see Table VIII) The new database will be updated using Delphi techniques. Simplifications and a reduced number of data elements will hopefully encourage the Branch Schools to regularly update their communications needlines in order to keep the database viable. The data elements discussed below are the most probable and closely resemble the data elements that are discussed in the Message Vector section. The Communications Module only needs the approximate load over each circuit to give a good "ball park" estimate of the probability of blocking and the average delay time.

Once the entire COMSR, to include voice, record traffic, and data modes is updated a valuable database for ALIM will exist. Notice elements six and seven, these elements depict a type of price tag or value for each message. The values are actually determined by the TRADOC Branch School in conjuction with the Combined Arms Center on a message by message comparative basis.[4]

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[3] Ferguson, Michael., GS 13, USASIGS, Ft. Gordon, Ga. , Telecon 28 March 84, with author.

[4] For more information see CGVS Dynamic Value Determination for potential usage.

TABLE VIII

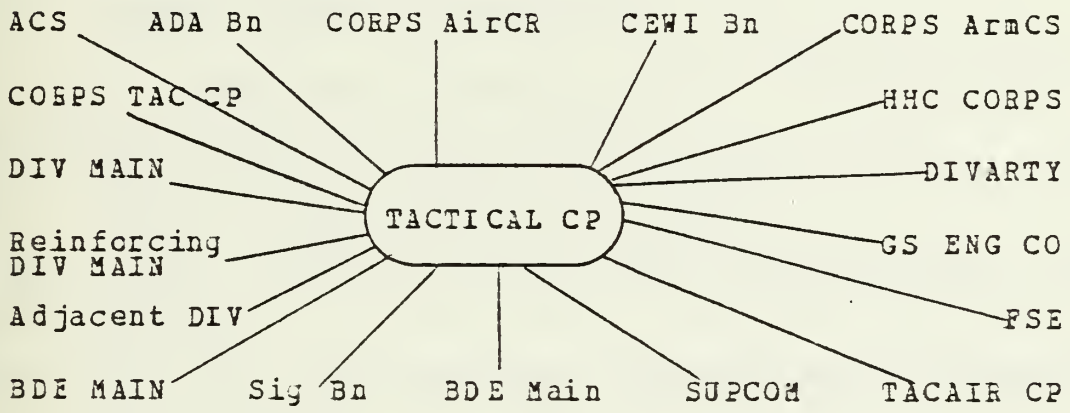
Table of Automated Systems Data Elements

1. Sender TOE TOE Multiplier Para Number Para Multiplier
   Line Number Line Multiplier
2. Receive TOE TOE Multiplier Para Number Para Multiplier
   Line Number Line Multiplier
3. Purpose Code
4. Mode - Data
5. Traffic Field # transmissions length of transmission # of bits
6. Speed Of Service Required: Perishability of Information due to
   things like hardware synchronization
7. Cost of Failure - Critical - TOE Mission Fails, Indispensable -
   TOE Mission Severely Degraded, Essential - Hampers Mission
8. Classification Level
9. Specific Communication Equipment to send traffic over - Telephone,
   FM, PLRS ,MC Satellite
10. Number of Messages per day
11. Range Code - Distance from Sender to Receiver in terms of hex grids
12. Interoperability for Communications Need - two different data system,
    or non US Army system send data device
13. Receive data device
14. Zone Code - Area of Operation of sender
15. POS NAV code - regulations for mutual, or cooperative or no POS NAV
16. Proponent School Code

Table IX depicts the COMSR Bubble Sort program for a typical Tactical Command Post. It is the responsibility of the Routing Submodule to initially select the routes over which all COMSR traffic flows. For instance, the heavy voice and data load between the Tac CP and Main (see Appendix D) will be routed primarily via the multichannel LOS VHF system connecting the two nodes.

TABLE IX

COMSR Needlines: Tac CP to Other Users



The COMSR database has files which give the parametric details of all traffic passing through, between, or within nodes and subscribers, respectively. These parameters are necessary to match with the Routing Submodule parameters. A few file definitions are in order:

Typical Unit Number (TUN) File: A file used in conjunction with a COMSR database. Its primary function is to provided a convenient index for all unique, Table of Organization, and Equipment (TO&E) specific units.

SPEC...Specific Unit File: A file used in conjunction with the COMSR database which organizes the units contained in a database into a desired force structure.

Inter Unit CCMSR File: A communications requirement (file) to pass information between two or more individuals, assigned to different TOE units, and not in immediate proximity to each other which must be satisfied to accomplish assigned mission.

Intra unit CCMSR File: A communications requirement (file) tc transfer between two individuals, assigned to the same TOE unit, and not in the immediate proximity to each other, which must be satisfied to accomplish assigned functions. [Ref. 19]

3. General Scheme of Operation

The Database is loaded into the Routing Submodule. The Routing Submcdule then provides:

1. Communications traffic requirements between signal centers (nodes) prior tc routing.
2. Traffic summaries along links between nodes after rcuting.
3. Lccal and long distance distribution of communications traffic.

Once the traffic has been routed, arrival rates and service rates during the worst case "busy" hour can be determined for each circuit. The parameters needed to determine blocking probability and expected delay time are the arrival rate, service rate, type queue service, and, if more than one communication node is involved, a list of sequential queues (nodal switchboards). Given the blocking probability for the BFI traffic that is being explicitly modelled, Monte Carlo methods can determine if the message will be blocked. If the message is blocked, then add the delay time to the message vectors elapsed time clock

parameter. The message vector is then forwarded to the next queue where blocking probability and delay time are determined.

Incidently, the Army currently owns SIMCE or Simulation Communication Electronics Model, a computer based simulator model designed to simulate military communications architecture using CCMSR. However, SIMCE requires manually inputting all routing procedures[5] for each message, is inflexible to changes in network design, and has not been used successfully in ten years.

4. Analytics

Restated in more familiar terms, the critical questions that need to be addressed by this submodule are:

1. What is the probability that a communications user will find all channels busy?
2. What is the average delay time experienced if user finds all channels busy?

A major premise of this thesis is that it is futile to attempt to explicitly and exactly simulate communications flow through the Army Tactical Communications System with its three generations of electronic componentry and the equally variable future communications architecture as described by the Integrated Tactical Communications System 1976 ,1979, 1981, 1984, and future revisions. By examining the processes of the communication traffic, we can apply Telephone Traffic Theory (TTT) in order to obtain an approximate answer to our questions at a great savings of manpower and computer processing time. If the communication module is built in this manner, then it will be possible to parametrically input whatever technical specifications,

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[5] Discussion of a simpler, more responsive routing procedure is presented later in the Routing section under Minimum Spanning Tree.

equipments, or architectures that are being analyzed by simply varying the channel capacity, routing, speed of transmission, load, etc., that effect the arrival and service rates. Petr Beckmann, a noted TTT specialist, feels:

> The facilities needed to realize a telephone conversation between two subscribers of a network are exceedingly complex. One of the pleasant aspects of Telephone Traffic Theory is the fact that one need not excessively concern himself with these complexities in detail. (Most equipment)...function and details of operation are irrelevant to traffic theory. [Ref. 10]

5. Overview Of Congestion Algorithm

Messages are assumed to have Poisson arrival and Exponential service times. These assumptions are validated in numerous studies of telephone traffic data and do not present a controversial issue to communications experts.

In a communications network every nodal switchboard acts as a separate queue. The traffic flowing through the links stops at each ensuing switchboard (even if for only a micro second). In Figure 3.5, when the G3 picks up his phone, he may or may not receive a dial tone from the switch at the TAC CP. The switchboard represents a type of queue called a terminal queue. Assuming he gets a dial tone, he dials his first four prefix numbers. He may or may not receive a busy signal from the Command Node switchboard. This switch represents a queuing process called a network trunk queue. This process goes on for as many switchboards as are transitted. Obviously, the more nodal switchboards transitted, the higher the probability of being blocked, and the longer the expected delay time. This process is intuitively appealing, especially to readers who have used the Autovon system.

There are two basic types of switching service facilities as shown in Figure 3.6 . In both, subscribers are assumed to call at random times and thus occupy one of the available service channels. If the call arrives at a time when all the lines are busy, the subsequent treatment depends on the type of service system for that circuit. If these calls are turned away (e.g. a busy signal) the system is called a *loss system* because it loses all memory of calls arriving at times when all the channels (see Figure 3.6 A) are busy. On the other hand, calls arriving when all the channels are busy may form a queue and wait until service becomes available upon successful completion of service in the channels. This occurs for telephone devices that *hold blocked calls*. Such systems are called *delay systems*. If the number of customers in a holding queue is limited (e.g. based upon storage capacity or number of automatic rerout tries), the result is called a combined loss and delay system.

The behavior of any queuing service system is derived from the utilization factor or traffic intensity (denoted ρ), which is the call rate (denoted λ) divided by the service rate (denoted μ). The *load*, a basic concept of traffic, is the product of the call rate and the mean holding time. Although the load is obviously a dimensionless quantity, the load is measured in units called *ERLANGS*. For example, a certain type of telephone line that handles 50 calls per hour with a mean duration of 3 minutes (1/20 of an hour), has an equipment load of 50x(1/20)= (ρ) =2.5 Erlangs.[6]

---

[6] One of the classic results in the study of telephone traffic is the formula for delay given by Danish engineer A.K. Erlang in 1917. This is for a random call input to a fully accessible simple trunk group with the holding time exponential and calls served in the order of arrival.

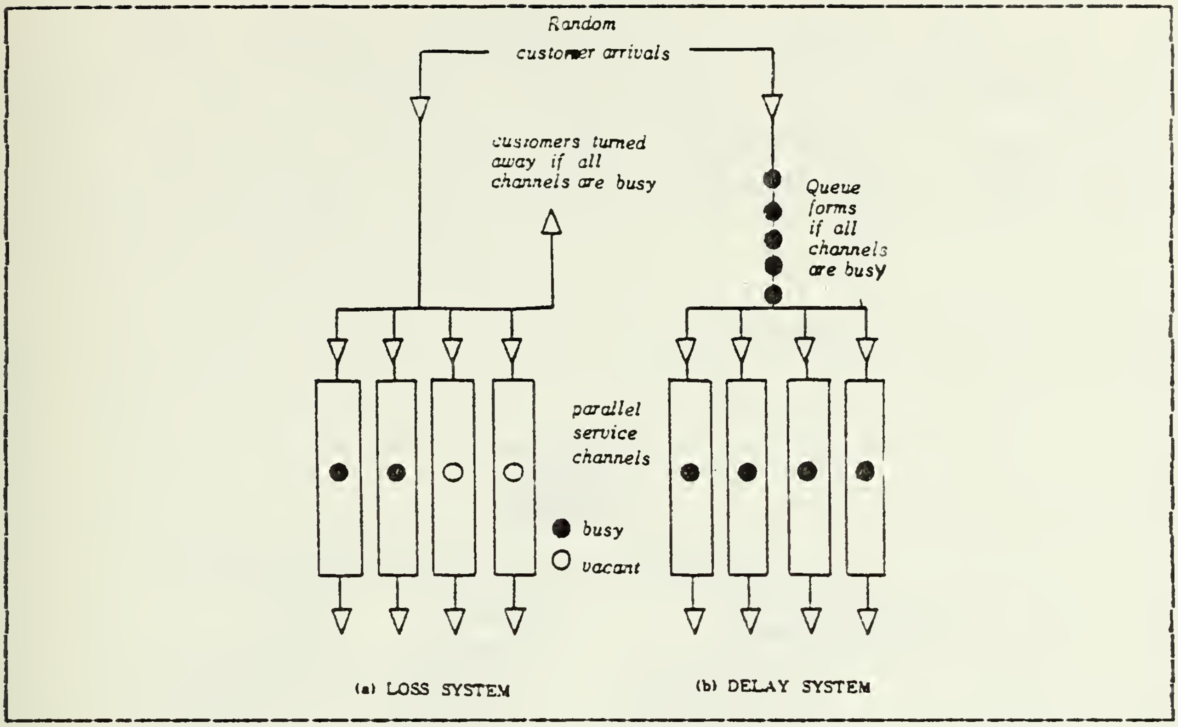

Random customer arrivals
customers turned away if all channels are busy
Queue forms if all channels are busy
parallel service channels
● busy
○ vacant
(a) LOSS SYSTEM
(b) DELAY SYSTEM

Figure 3.6 Type Service Facilities

TABLE X

Service Available to Subscribers

Loss Systems	Delay Systems
Routine Calls over S/C Net Radio	Higher Precedence Calls over S/C Net Radio
Routine Telephone Calls over Common User System	Higher Precedence Calls over Common User System
	Store and Forward Data Switches
	Air Defense Communications System

BF network congestion is a critical part of the Level III high resolution methodology. In this submodule we learn just how grievously the environmental degradation, enemy interdiction, and friendly communication loads effect the message transit times.

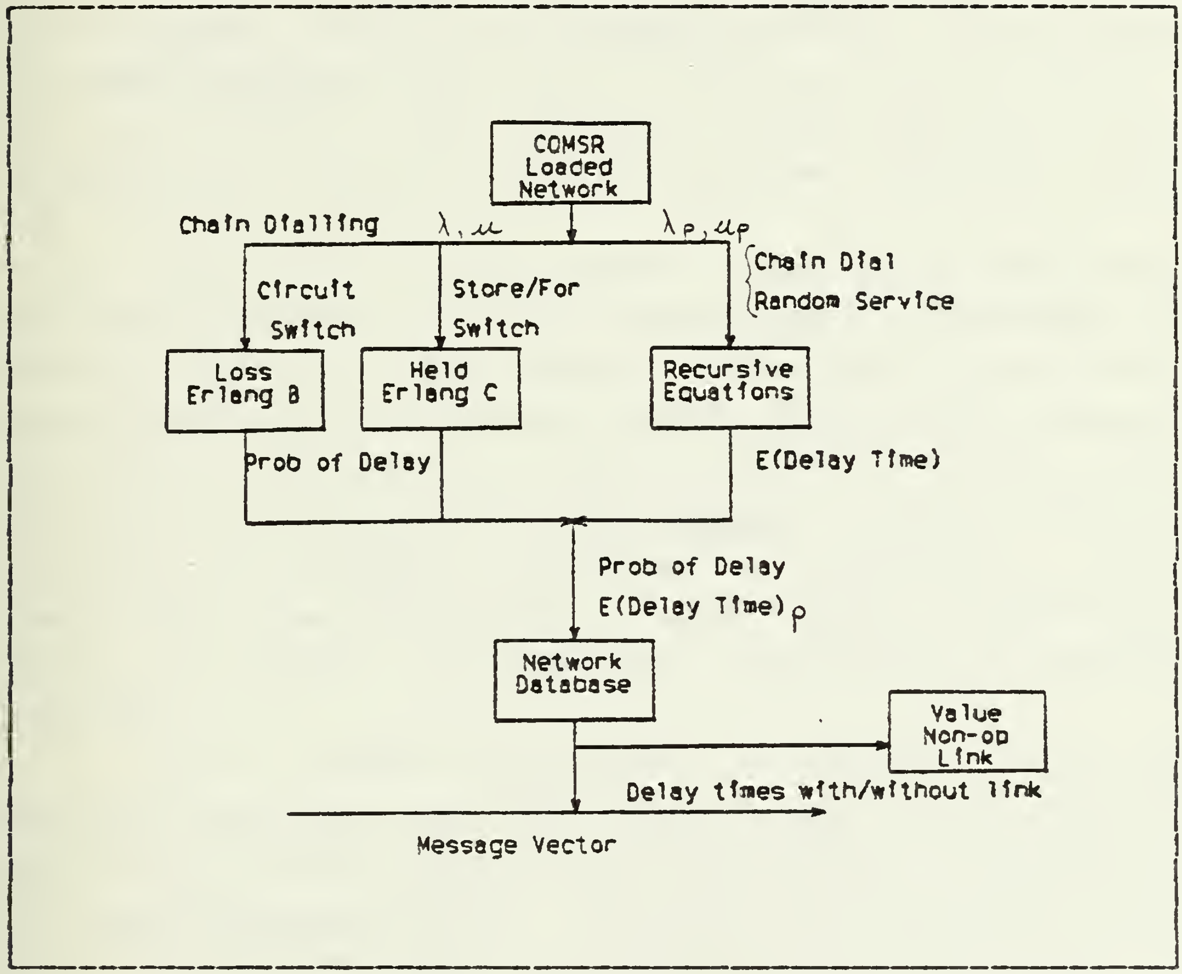


Figure 3.7 Network Congestion Algorithm

As seen in Figure 2.2, the non-operational links resulting from either environmental degradation or enemy interdiction are input into a Non-Operational Record in the Network Database. If enemy interdiction causes catastrophic communication degradation within an area then the

Operational Network Record is updated. A massive change to the Operational Network would trigger a need for a complete review of how the Routing Submodule loads the network (i.e. a complete run of the ROUTE Submodule again). If minor non-availabilities occur, then the Reroute Process informs the Non-Operational record. This results in the message transitting the first alternate route, which is already stored in the message vector. The Reroute Submodule then informs the Loaded Network Record and the arrival rates of the down link are added to the alternate routes using the same decomposition technique that is discussed later in Figure 3.9.

The arrival and the service rates can be maintained as either aggregate or as individual rates by precedence. As seen in Figure 3.7, if we desire a lower level of resolution (aggregated across precedence levels) then the link's aggregate arrival and service rate is used and Blocking probability is determined by the Erlang B (Loss Service) algorithm or by Erlang C (Held Service) algorithm. Delay times would then be computed. Lower levels of resolution would be helpful in analyzing architectural planning problems.

If a higher resolution is required then the Recursive equations (see Table XIII) would be used with the arrival and service rates by precedence being forwarded from the Loaded Network Record. Both the lower and higher resolution procedures output a probability of delay and an expected delay time. This information becomes parameters of the message vector. Higher levels of resolution are helpful in analyzing individual message audit trails and system values by precedence.

6. Theoretical Justification for Traffic Analytics

a. Simulating Loss Service Facilities in Army switches

Our G3 (see Figure 3.5) has selected the voice telephone means of communicating with a Brigade S3 for a routine call. This action puts him into the circuit switch system which utilizes the Loss service discipline. In the case of telephone calls, the customer arrivals are given as call initiations; the service channels are the available circuits, and the service times are the holding or call duration times. No queues as such exist since Army circuit switching facilities have no provisions for holding calls that cannot be immediately connected. These calls are cleared in one of two ways: they are either rejected by a busy signal, or returned to the previous switch for rerouting. In either case, the calls are lost to the facility being negotiated [Ref. 10].

In TTT, the ERLANG B formula gives the probability that *k* out of *c* parallel service channels are busy given the utilization factor or offered load. The probability that all *c* channels are busy and that, therefore, an offered call will be lost is seen in Equation 3.1 . A short Fortran program for determining this is given in Table XI .

$$P_{LOSS} = \frac{\dfrac{\rho^{C}}{C!}}{\displaystyle\sum_{K=0}^{C} \frac{\rho^{K}}{K!}} \qquad (3.1)$$

C = #BUSY CHANNELS

K = #TOTAL CHANNELS

TABLE XI

Determination of Erlang B Values

```
C   TAPE 5 = INPUT,  TAPE 6 = ØUTPUT
          REAL LØAD, LMIN, LMAX, LSTEP
          INTEGER C, CMIN, CMAX, CSTEP
          DIMENSIØN FCTRL(insert CMAX or greater)
          READ (5, 10) LMIN,LMAX,LSTEP,CMIN,CMAX,CSTEP
       10 FØRMAT(                    )
          FCTRL(1) = 1.
          DØ 20 J = 2, CMAX
          RJ = J
       20 FCTRL(J) = RJ*FCTRL(J - 1)
          DØ 60 C = CMIN, CMAX, CSTEP
          WRITE (6, 30) C
       30 FØRMAT(include desired headings here)
          MMAX = LMAX/LSTEP
          MMIN = LMIN/LSTEP
          DØ 60 M =  MMIN, MMAX
          AM = M
          LØAD = AM*LSTEP
          SUM = 1.
          DØ 40 K = 1, C
          TERM = (LØAD**K)/FCTRL(K)
       40 SUM = SUM + TERM
       45 PL = TERM/SUM
          WRITE(6, 50) LØAD, PL
       50 FØRMAT(           )
       60 CØNTINUE
          STØP
          END
```

b. Simulating Held Service Facilities in Army Switches

Our G3 has selected the computer terminal to send electronic message traffic to the Brigade S3. This action puts him into the Store and Forward Message Switch System that utilizes Blocked Calls Held service discipline.

The calls that do not find an idle facility are blocked, but are held and delayed in order to be connected when a path becomes available. In the simplest case, calls are held by a human telephone operator or a memory device. The switch holds the originator's line or promises to call back when a free line is available. The subscriber who, on being blocked by an automatic facility, redials his call at frequent intervals until his call is connected, in effect, also joins a queue of subscribers waiting for Held service

[Ref. 10]. The G3 uses a type of Held service if he chain dials until he gets an available circuit. Chain dialling is a reasonable assumption especially if the call is of a higher level of urgency (as all marginal traffic will be) and the message must get through to the distant end.

For telephone, data, or teletype traffic, the service held queue can be described by the Erlang C formula. For large numbers of calls the probability of blocking is equal to the probability of delay, in other words the probability that all channels are busy equals the ratio of delayed to offered calls in Equation 3.2 . A short Fortran program for finding Erlang C Values is in Table XII .

$$P_{DELAY} = \frac{\rho^{C}}{\rho^{C} + C!\left(1-\frac{\rho}{C}\right)\sum_{K=0}^{C-1}\frac{\rho^{K}}{K!}} \qquad (3.2)$$

C = #BUSY CHANNELS   K = #TOTAL CHANNELS

If we are looking for a way to find the delay times for each precedence level we may use the following concepts.

7. High Resolution Candidate

a. Precedence Level, Preemptive Resume Queue

Introducing a priority structure into a message set influences the expected value of the time that each precedence group spends in the queue. Intuitively it is clear that a priority system would allow higher precedence messages to pass faster than a non-priority discipline and conversely lower precedence messages pass slower than in a non-priority system. (See Figure 3.8).

TABLE XII

Determination of Erlang C Values

LINES 1-40 FROM TABLE XI

```
 40 DIMENSIØN F(insert C2 or greater)
 50 READ L1, L2, L3, C1, C2, C3
 60 LET F(1) = 1
 70 FØR J = 2 TØ C2
 80 LET F(J) = J*F(J - 1)
 90 NEXT J
100 FØR C = C1 TØ C2 STEP C3
110 PRINT "C = " C
120 PRINT "LOAD", "BLOCK.PROB."
130 FØR L = L1 TØ L2 STEP L3
140 IF L > C THEN 230
150 LET S = 1
160 FØR K = 1 TØ C
170 LET T = L↑K/F(K)
180 LET S = S + T
190 NEXT K
200 LET P = L↑C/(L↑(C+1)/C+F(C)*(1-L/C)*S)
210 PRINT L, P
220 NEXT L
230 NEXT C
240 DATA        (insert values needed in line 50)
250 END
```

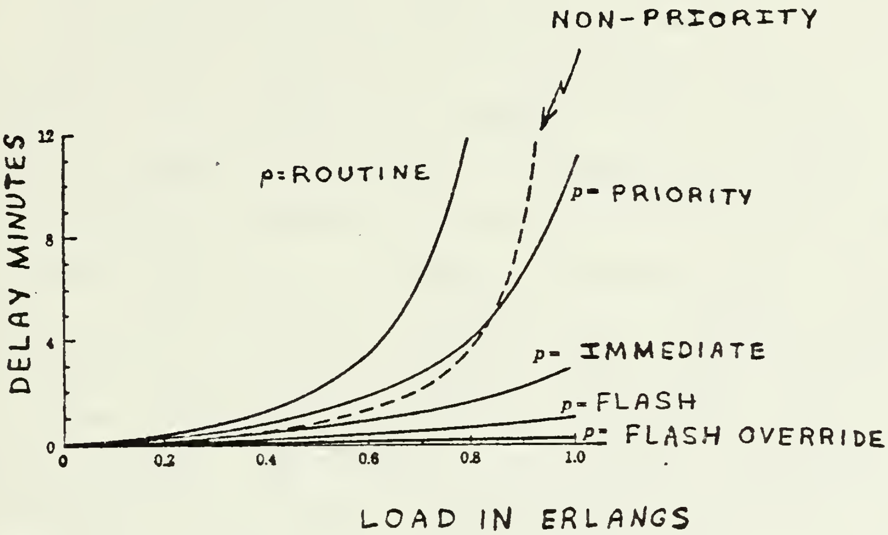
```
      RC = C
      IF(LØAD.GT.RC) GØ TØ 60
```

and replace statement 45 and the next by

```
45    PD = (LØAD**C)/(LØAD**(C+1)/RC+FCTRL(C)*(1.-LØAD/RC)*S)
      WRITE(6,50) LØAD, PD
```

b. Required Operational Assumptions

The use of Telephone Traffic Theory seems to be an ideal approach for analyzing the complexities of determining delay times in tactical communications systems. Several assumptions are required in order to use queue analysis techniques. One assumption is that if a subscriber receives a busy signal, then he will hang up and continue to redial until connected to his distant end. This assumption allows the queue discipline to be one of "blocked calls held" instead of "blocked calls lost". This step is justified by the studies of J. Riordan and R. Wilkerson which resulted in numerous publications in the Bell System Technical Journal. The most significant is an article by Riordan in which he contrasts the Erlang C queue with random service queue. In determining delay times for random order of service, the article reports that the mean delay time is



[Ref. 11 p80]

Figure 3.8 Priority vs. Non-Priority Queues

approximately the same as for an ordered FIFO discipline. This is remarkable and convenient since the E(delay time) for random order of service is not "closed form" solvable but FIFO service is solvable [Ref. 8] and [Ref. 9]. Petr Beckmann states that:

> Random order of service in telephone traffic occurs when subscribers hold their own calls by constantly probing a busy facility (outside lines serving their extensions, an engaged number, long distance trunks, etc.). The subscriber whose attempt comes first just after a line has become available is so favored only by chance. More important, modern telephone equipment includes switching systems where control equipment for setting up paths is

common to several switching devices; and this control equipment handles delayed calls in random order. [Ref. 10]

Another important assumption concerns the independence of interarrival times and message lengths at queues. A recognized difficulty arises whenever networks of (tandem) queues are analyzed. This difficulty rests with the assignment of a delay to each message. This assignment gives rise to a dependency between the interarrival times and the lengths of adjacent messages as they flow from one queue to the next queue. One can attempt to satisfy this difficulty by refering back to the original G3 message generator discussed previously (see Figure 3.5). His messages are assumed to be Poisson arrivals even though his message interarrival times and lengths are indeed dependent. The Poisson assumption is valid because the collective interarrival times and length of messages generated by the entire population of subscribers exhibited an independence, i.e. the message lengths generated by the G3 at Corps are completely independent of the arrival times of messages generated by the G1 at Division or the S2 at the ADA Battalion, etc..

Carrying this reasoning forward to analyzing the internal, nodal queue to nodal queue network, one can also make this independence assumption. There are from 12 to 96 channels transmitting or receiving messages from one node. The multiplicity of circuits in and out of each node considerably reduces the dependency between interarrival times and message length of the consecutive messages as they enter subsequent queues within the network. [Ref. 11]

Leonard Kleinrock, a noted TTT theorists, states the Independence Assumption as follows:

> Each time a message is received at a node, a new length "v" is chosen for this message from the following probability density function in Equation 3.3 .

$$P(\nu) = \lambda e^{-\lambda \nu} \tag{3.3}$$

$$\lambda \equiv \text{ARRIVAL RATE}$$

> It is clear that this assumption does not correspond to the actual situation in any practical communication net. Nevertheless, its mathematical consequences result in a model which accurately describes the behavior of the message delay in many real nets.

He validates this assumption through simulation in [Ref. 11 pp 50 - 56]. This equation is imbedded in the theory of the Recursive equations and is not a computational requirement of this submodule.

The bottom line is that for a large number of calls within the overall system and the above assumptions, it is possible to analyze a random order of service problem such as a subscriber continuously redialling if he gets a busy signal using TTI, and in particular using calls held service. We can analyze a tandem queue situation by looking at each nodal queue individually.

By decomposing the arrivals (allowable by the Poisson Assumption) into a number of branches that can be analyzed as single server queues (see Figure 3.9), it is possible to make maximum use of the work accomplished by Cobham, White, and Christie. Additional criteria for this queue model are that there are a total of P different precedence classes. The messages from each precedence class arrive in a Poisson stream at a rate of (λp), each message from class P has an exponential service time with mean ($\frac{1}{\mu_p}$).

The discipline considered in this model is the fixed priority system with preemption. If a message of lower priority is preempted by a higher priority then it "resumes" from the point of interrupt to complete the lower priority message once the higher priority has been completed [Ref. 11 pp.73-74]. The assigned priority remains fixed in time. These criteria do not remove us from the reality of

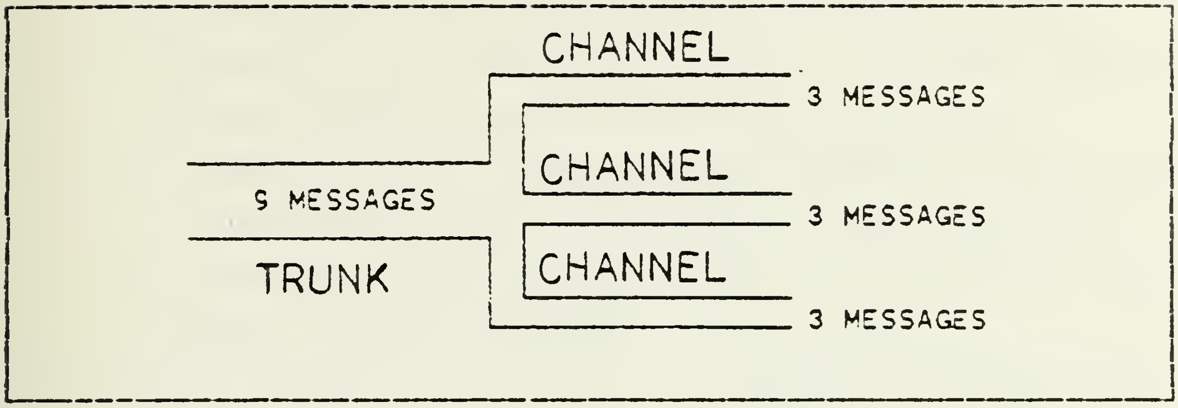


Figure 3.9 Decomposition of Arrivals

military telephones systems. On the contrary military priorities are fixed into Flash Override, Flash, Immediate, Priority, and Routine precedence levels. Any queued Flash has a higher priority than any queued Immediate regardless of the message entry time into the system. If the Immediate caller is preempted then the caller would redial his call, get a completed circuit if a channel was free, and continue with his conversation.

The equations that are used are defined recursively as follows in Table XIII . An important concept that effects the arrival rate is the determination of the Busy Hour. For the busy hour to be more realistic each functional area would need to designate the percentage of traffic sent and received over each hour of a twenty-four hour period. This is possible, however, not discussed in this thesis. The busy hour slice is 15 % of COMSR traffic and represents the communications system peak load hour which may or may not be an individual functional area peak load time.

c. Procedure For Determining Mean Delay Times

1. Determine the busy hour traffic by taking 15% of total traffic over the link being analyzed.
2. Determine (λ) from # messages transitting link (.ie messages transitting per busy hr / link capacity).
3. Determine average service times by precedence then (μ_p) = 1/(service time)
4. Use recursive equation to determine average delay, D(ip), for each precedence level for that link.
5. Examine route chosen for BF traffic. Sum the average delays for particular precedence across all transitted links, $(S) = \sum_{i=1}^{N} D_{ip}$, i = LINKS OF ROUTE
6. Draw random variable from EXP (S), that is actual delay time for that message

TABLE XIII

Recursive Equations

$D_P \equiv$ Delay Time for the P th Precedence Level

$$\lambda = \sum_{P=R}^{FO} \lambda_P \qquad \rho = \sum_{P=R}^{FO} \rho_P = \frac{\lambda}{\mu} \qquad \rho_P = \frac{\lambda_P}{\mu_P}$$

FO - FLASH OVERRIDE, F - FLASH, I - IMMEDIATE, Pr - PRIORITY
R - ROUTINE

$$D_{FO} = \left[\frac{\rho_{FO}}{\mu_{FO}}\right] \div \left[1 - \rho_{FO}\right]$$; Can be used for $D_{aggregate}$

$$D_F = \left[\frac{\rho_F}{\mu_F} + \rho_{FO}\left(\frac{1}{\mu_F} + \frac{1}{\mu_{FO}}\right) + \rho_{FO} D_{FO}\right] \div \left[1 - \sum_{i=F}^{FO} \rho_i\right]$$

$$D_I = \left[\frac{\rho_I}{\mu_I} + \sum_{i=F}^{FO} \rho_i \left(\frac{1}{\mu_I} + \frac{1}{\mu_i}\right) + \sum_{i=F}^{FO} \rho_i D_i\right] \div \left[1 - \sum_{i=I}^{FO} \rho_i\right]$$

$$D_{Pr} = \left[\frac{S_{Pr}}{1 - S_{Pr}} \sum_{i=Pr}^{FO} \frac{\rho_i}{\mu_i} + \frac{\rho_{Pr}}{\mu_{Pr}} + \sum_{i=I}^{FO} \rho_i \left(\frac{1}{\mu_{Pr}} + \frac{1}{\mu_i}\right) - \rho_R D_R\right] \div \left[1 - \sum_{i=I}^{FO} \rho_i\right]$$

$$D_R = \left[\frac{S_R}{1 - S_R} \sum_{i=R}^{FO} \frac{\rho_i}{\mu_i} + \frac{\rho_R}{\mu_R} + \sum_{i=Pr}^{FO} \rho_i \left(\frac{1}{\mu_R} + \frac{1}{\mu_i}\right)\right] \div \left[1 - \sum_{i=Pr}^{FO} \rho_i\right]$$

$$S_j = \left[\sum_{i=j}^{P_r} \rho_i\right] \qquad S_R = \left[\rho_R\right] \qquad S_{Pr} = \left[\rho_R + \rho_{Pr}\right]$$

TABLE XIV
Numerical Example

11-01 LINK

		FO	F	I	P	R
# transmissions		2	1	3	20	40
(12 channels)	λ_p	.167	.083	.25	1.67	3.33
	μ_p	60	60	30	15	12
	ρ_p	.0028	.0014	.0083	.1113	.278
	$(\rho_p)/(\mu_p)$	.00005	.000023	.00028	.0075	.023

$D_{FO} = ((.00005 + 0 + 0) / (1- (.0028)) = .18$ seconds

$D_F = ((.000023 + (.00093) + (.00000014)) / (1-(.0014 + .0028)) = .42$ seconds

$D_I = (.00028+(.00021)+(.0000003024)) / (1-(.0083+.0014+.0028))= 1.78$ seconds

$D_{P_r} = (.0075 + (.00104) + (.0000044)) / (.8762) = 35.2$ seconds

$S_j = \sum_{i=j=R}^{FO} \rho_i = .402$

$D_R = (.6722(.0308) + .023 + (.018)) / (.8762) = 253.5$ seconds

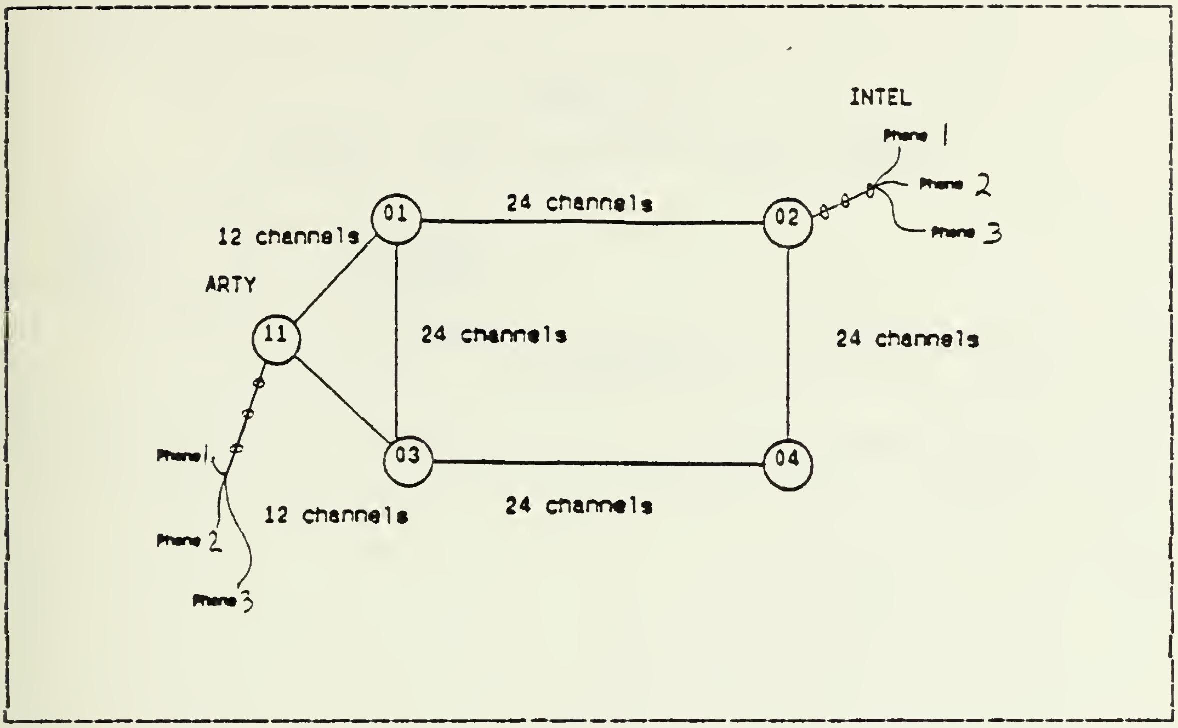


Figure 3.10 Tandem Queue

If the BF Artillery was making a flash override call to BF Intelligence the routing in this example would be (Phone 1-11-01-02-Phone 2). To calculate the expected delay time for phone to phone connect just sum the expected delay times for each link as determined above and listed in Table XV . If only one call is being simulated then make a random draw using Exponential with mean 2.28 seconds. If several calls are expected (in the long run) just use the average 2.28 seconds.

TABLE XV

Example Flash Override Delay Times

Phone 1-11	1.00 sec
11-01	.18 sec
01-02	.10 sec
02-Phone 2	1.00 sec
	2.28 sec for connect time from Phone 1 to Phone 2

IV. COMMUNICATIONS GENERALIZED VALUE SYSTEM

A. INTRODUCTION

The Air-Land Interdiction Model will have an overall Value System. The discussion that is to follow concerns the Communications Generalized Value System (CGVS), a separate entity, not to be confused with other combat functional area Value Systems or the overall Air-Land Value System. The CGVS provides the means of determining the utility of each component of the communications architecture in both the static and dynamic states. The CGVS (see Figure 2.1) will be able to provide to other submodules the quantitative and qualitative information necessary for planning future augmentations or reductions of currently deployed assets, or for prioritizing and allocating resources to restore degraded assets.

The CGVS submodule, analogously speaking, is the sensory inputs of the nervous system of communications. The CGVS provides numbers to the brain so decisions can be made. Each communication link derives value from how efficiently each message level of urgency (precedence) is handled, and that links role within the context of the entire communications architecture. The intent of the CGVS is to measure only marginal traffic created by BIF because the ALIM is interested only in Air-Land Interdiction units. The model has the capability to measure background traffic value if required. Every message is destined for a certain part of the system body; the addressing and urgency decide which artery the message flows. Unlike the human body, this message can be stored or rerouted if a part of the system is temporarily incapacitated. This information flow is

accomplished as transparently as possible to the message sender or receiver. The value of each communication link is directly determined by the users through the messages they send. Based on the communications required by the users, the communications planning staff literally builds from the ground up the communications to support the requirements. All the network building or rebuilding decision logic find their justification in the CGVS. Usage of generic systems or allocations of additional resources of any type are directly determined using data from the CGVS. There are no models which currently utilize any sort of CGVS to make decisions of high resolution for communication play. The CGVS is essential to credible examining of comparative decision making in a high resolution environment.

B. CGVS CONCEPT

The CGVS data used for designing and maintaining communications support is broken down into areas based on time and event sequencing; the pre-combat static phase and the combat dynamic phase. Standing operations orders, based upon historical deployment of systems over years of exercise play, exist for deployment of communications systems. Planning staffs have created OPLANS based upon potential tactical scenarios and expected potential value of communication links to mission accomplishment. The planners know generally who must be supported, however the unit locations and volume of traffic vary considerably based upon individual unit's time sequenced contribution to the ongoing battle. For example, a high priority communications link ties Theater Main to Corps Main from the start of the war. One might assume that this link would have tremendous dynamic value because this link ties a resource allocater to a heavy resource user while in the midst of mortal combat.

Quite to the contrary, Corps Main cares little about its ability to talk to higher headquarters in the early stages. Corps Main is concerned with the battle situation for the first few days and is capable of fighting at this time relatively unsupported by Theater. The link maintains a high static value. As the days wear on, this link obviously becomes much more critical to Corps for allocation of replenishment resources from Theater, i.e. the link attains a high dynamic value with time.

What is the Value of this link? This is a difficult concept to grasp because the value changes over time and event occurrences. What is the value of alternative routes to this link? Should reconstitution of this link take place when degradation occurs? When is the value of this link so high that Red Forces must attempt interdiction? How do we quantify this value over time? These research questions must be resolvable by analysis of the CGVS output. What stands out most at this point is that the initially deployed network links have a potential value based on historical usage and as the battle progresses, the link values increase or decrease in value over time based on user demand generation and the success of enemy interdiction efforts.

Picture a pipeline through which passes general communication traffic having relatively small values. If this traffic is delayed for a period of time the value does not deteriorate or reduce the war fighting capability. Impose on this link traffic of a newly arrived unit called the All Source Analysis Center which has traffic for the Corps TOC (Figure 4.1).

When entities of high value are placed on this link the message traffic and corresponding message value jumps enormously. Should this link be overloaded or incapacitated, the alternate routing for this needline increases in value dramatically. The Expected Delay Time would definitely

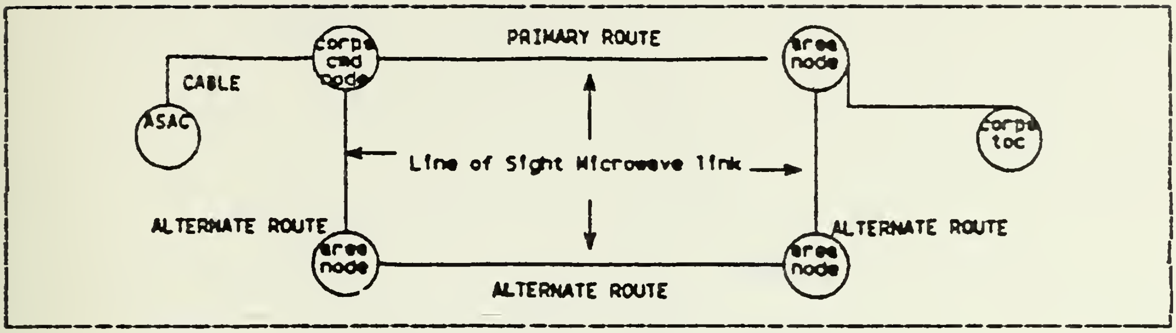


Figure 4.1 ASAC to CORPS TOC Needline Routing

increase because the more "metal", the lower circuit availability, and higher the probability of delay.

Congestion or overloading on these links may on occasion result in the devaluing the time sensitive messages. The devaluation may be to the point where the decision to still attack a certain target may be reversed in favor of a now more valuable target. (Figure 4.2)

The new Communications Support Requirements Database[7] will provide guidance as to the comparative value that each functional area message possesses if it were delivered in real time. Examine Table VIII . This Table reveals data elements Six (Speed of Service and Perishability of Information) and Seven (Cost of Failure - critical, indispensable, essential, etc.). Element Seven could give us the initial value[8] (Vi) for Figure 4.2 . Element Six could give us the Exponential parameter needed to degrade the value of the message over time thereby giving us the final value. This Value Process is feasible, but it remains to be seen if the CCMSR database can gain the support needed to update and revalidate these data elements.

---

[7] This database was discussed in the Communications Degradation Submodule and further study should be conducted in this area.

[8] Using MADMAN (Appendix C), weighting techniques determine a value for critical, indispensable, and essential.

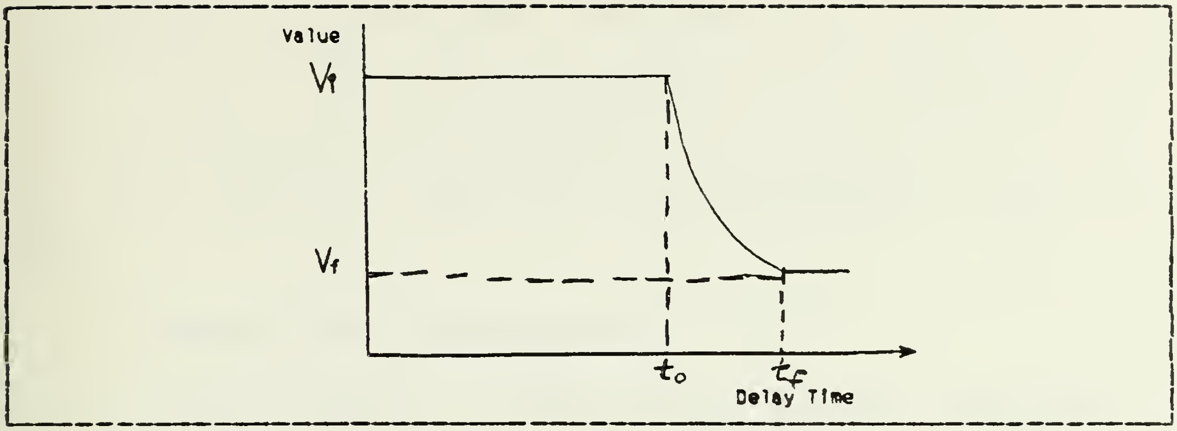


Figure 4.2 Value Degradation Over Time

The communication complexity in a war environment naturally generates many questions. The CGVS coupled with message vector audit trails will help answer them. But how is this elusive value found? Intuition suggests that message value should be calculated in the Communications Module by aggregating products of the number of messages times an urgency level (precedence) multiplier for each message over the link. However, this procedure ,although simple in design, reflects the point of view of the communications officer and not the subscriber. An amazing amount of "precedence creep" occurs when a subscriber needs to pass information quickly but is not authorized because of the requirements of each precedence level. On a fast moving, dynamic battlefield, information about when and where to resupply beans and bullets can be just as important as where to conduct an air strike in winning a battle. A value system that would lend itself to designing a communication network that minimizes delay times for all precedence levels is far more responsive to the subscriber than just saying a link is of such and such a value because 3000 routine messages passed through it in the last hour and were all delivered within the required 24 hour period. This section

will describe a system that will reward and punish networks based on time delay and not on minimum precedence aspiration levels. This value will become a key input parameter to the Reroute Submodule, the Reconstitution Submodule, the Network Grid and the audit trail of the Interdiction Model as a whole.

1. Static Value Determination

Suppose general mobilization follows a buildup to East-West tensions along the German border. According to most scenarios the first deploying organizations are the tactical Signal units supporting the Corps and Theater Communications Zone (COMMZ). The intercommunications grids required by wartime OPLANS are set up and functionally operative within three days. There are, as yet, few if any users of the tactical network. Most combat, and combat support units are preparing for deployment or waiting for political approval to deploy from their base Kasernes. They are still using the fixed communications supplied by the U.S. Army Communications Command or the Bundespost Phone System.

At this point in time, the tactical communications system has a potential value based upon the generic systems which have been deployed to support potential users. Although the communication grid has been designed symmetrically to reduce its susceptibility to enemy collection efforts, there are enough asymmetries to suggest that some nodes are more important than others. Certain types of radios are indicative of the importance of the users they support and of the importance of the internodal links to the success of the overall communication network. The potential value of these links and nodes is static because no users have been tied into the network.

The method used to derive the utility values of each component of the communication architecture is found through

TABLE XVI

Relative Entity Utility Value

(The higher the number the better)

Transmission	Utility Value to Network
Satellite Ground Stations	943
Microwave links	648
Mobile Sub Central	380
AM links	353
FM links	137

Terminal Equipment	Value
Circuit Switch	856
Record Traffic Switch	490
Network Control Elements	486
Commcenter/DSTE	194

a variation of the MADMAN Algorithm discussed in Appendix C. The basic unit of communication hardware and therefore planning is the circuit. The MADMAN Methodology provides a means to derive a single aggregated measure of effectiveness (MOE), a utility value, from various individual attributes for the circuit. Some of the attributes considered by the experts are equipment survivability, cost, mission essentialness, reliability, and capacity (see Table XXIV for details). The following procedure outlines the MADMAN input requirements that must be based upon communications and C2 experts opinions.

TABLE XVII

Static Value Determination Using MADMAN

1 . Define Alternatives

A1=satellite ground station
A2 = HF radio
A3 = microwave radio
A4 = FM radios
A5 = Mobile Subscriber Terminal

2 . Define Attributes

X1 = Channel Capacity
X2 = Skip Echelon Capability
X3 = Survivability
X4 = Reliability
X5 = Cost

3 . Construct a Pairwise Comparison of Attributes for weighting - Best Military Judgement using scale in Figure C.3.11.

	Benefit X1	Benefit X2	Benefit X3	Benefit X4	Cost X5
X1	1	2	2	5	1
X2	1/2	1	3	3	1/2
X3	1/2	1/3	1	1	3
X4	1/5	1/3	1	1	2
X5	1	2	1/3	1/2	1

4 . Construct (A x X) matrix - Goal : Given the following alternatives and criteria evaluate the alternatives .

	X1	X2	X3	X4	X5
A1	High	Excellent	Very Good	Good	High
A2	Low	Excellent	Poor	Average	Low
A3	High	Poor	Good	Excellent	Average
A4	Low	Poor	Fair	Very Good	Very Low
A5	Low	Fair	Good	Very Good	Low

5 . Assign Values for Interval Scale - Best Military Judgement using scale in Figure C.5.19.

	X1	X2	X3	X4	X5
A1	9	10	8	7	1
A2	2	10	2	4	7
A3	9	3	7	9	4
A4	1	2	4	8	9
A5	3	4	7	8	6

These attributes and others are weighted in pairwise comparisons. The potential role value or conditional value of circuits such as for nuclear release may in this manner be included as an attribute which considers "Potential Value". Once the S(j)'s, the scaled values in Table XVII , have been obtained then multiply the values by 1000 to derive more aesthetic utility values. As seen in Figure 4.3, by summing the individual values of the equipment employed and "on site" backup we can determine the static value of signal nodes prior to any traffic being passed.

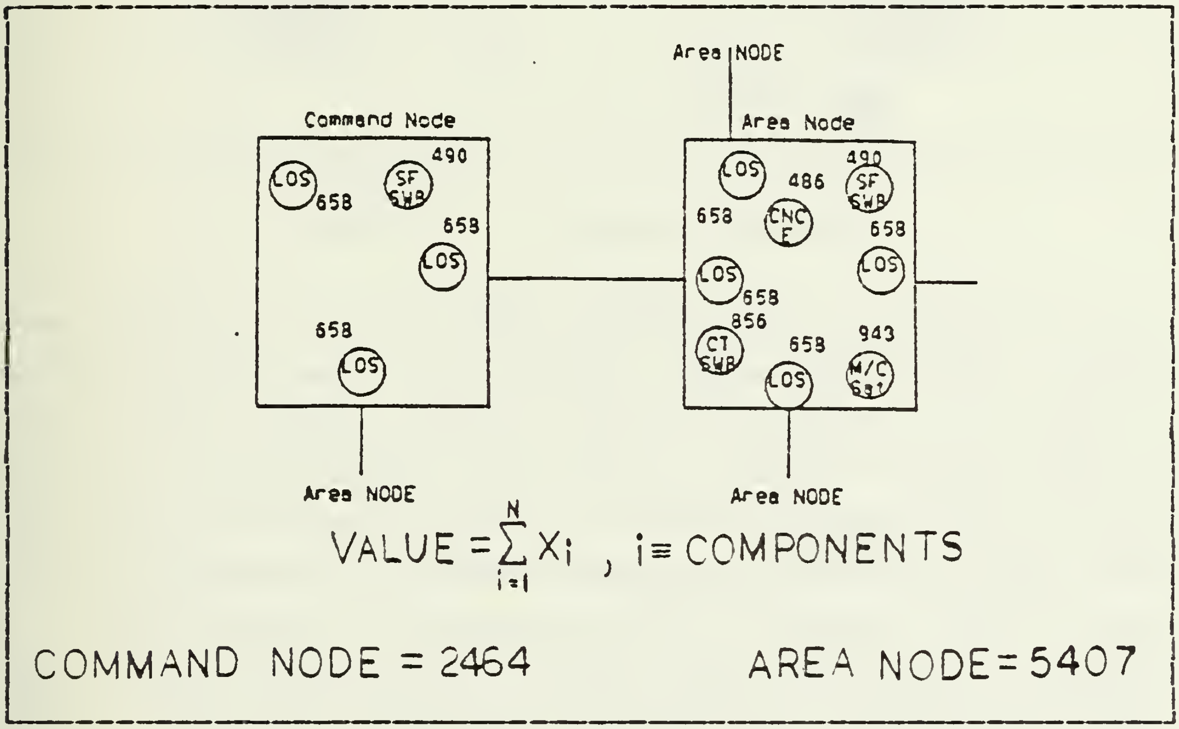


Figure 4.3 Static Value Example

2. Dynamic Value Determination

As the combat forces assume their battle positions and users begin to place demands on the communications

system, the value of links shift from the static value of hardware to a dynamic value based upon the actual message flow. Before describing the dynamic value system, we give a brief scenario as a message travels from the ASAC to the Fire Direction Center:

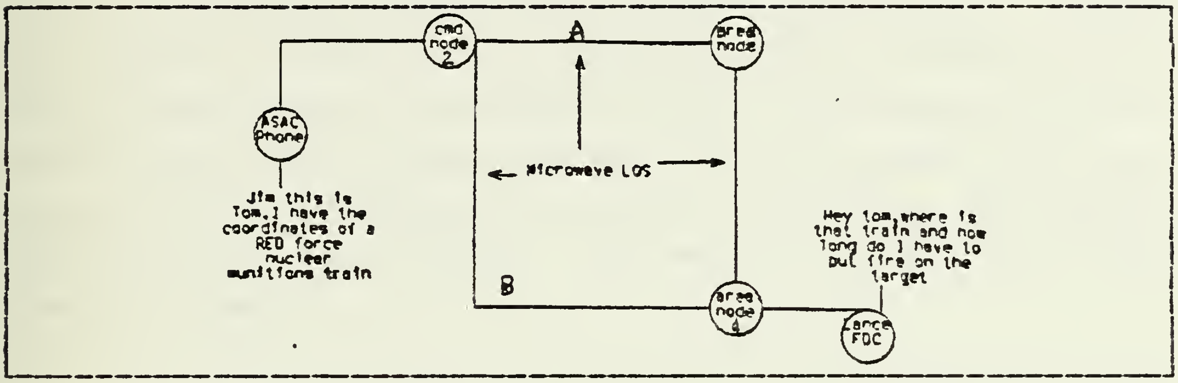

cmd node 2
A
area node
ASAC Phone
Microwave LOS
Jim this is Tom. I have the coordinates of a RED force nuclear munitions train
Hey Tom, where is that train and how long do I have to put fire on the target
B
area node 4
Lance FDC

Figure 4.4 Message Scenario

From Figure 4.4 we see that a phone number is punched into a digital telephone at the origin. This phone has a circuit path to the nearest circuit switch at Node 2. At Node 2, the call is demodulated and passed through a patch panel to the circuit switch. The call is routed automatically to Link A or B depending on circuit availability between nodes 2 and 4. The process is repeated until it reaches node 4 which has a circuit to the FDC. Given that the circuit is available, the whole process to include the dialing and immediate receiver pickup takes 7-15 seconds. The circuit is now complete and the user sends his message.

The value of this phone conversation is a function of the value placed upon it by the originator according to command guidance and the time it takes to turn the targeting information into fire allocation information. The ability to destroy a particular target by such and such a time has more value now than if the target is attacked 20 minutes

later, especially if the target has moved from its known location. The communication network is responsible for only a portion of this writer to reader time, the communications "expected delay time" that is maintained in the message vector.

A perfectly functioning communications system should result in no lost value to this target information. However time delays or failure to achieve required urgency precedence levels during the passage of this information not only reduces the value of this message but also points out shortcomings in the communication system that must be repaired immediately or circumvented. The value of the link at this moment in time:

$$\text{VALUE} = \sum \frac{W_p N_p}{D_p} \qquad (4.1)$$

where Wp is the weighted multiplier determined by MADMAN expert opinion.

Dp is the mean delay time for each precedence level over that link.

Np is the number of messages for each precedence over that link.

To aggregate these products for all messages over each link would tell us the dynamic value of each link for a specified period of time.

Its would be relatively easy to put counters into each link to determine Np and a time clock parameter to keep track of the total message time in each message vector to determine operational link values.

a. Operational Valuation

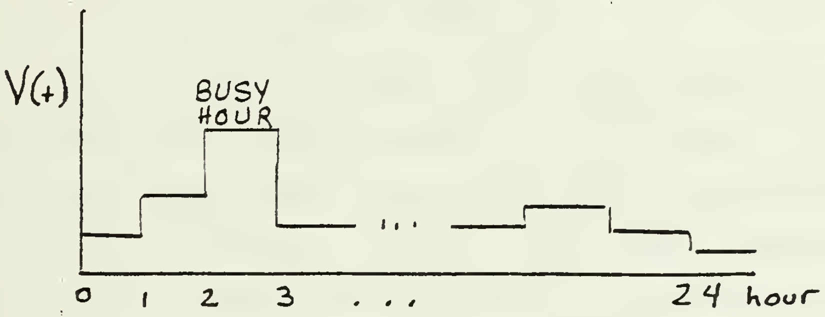


Figure 4.5 Hourly Depiction of Link Value Versus Time

The value of each link should be captured at some preselected time slice, say hourly. Using Equation 4.1, it would be possible to graphically represent the value over time for each link. It would also be possible to disaggregate the traffic loads into two groups: 1.) COMSR generated and 2.) BF generated. Using Equation 4.2, it would be possible to conduct sensitivity analysis by varying ($\underline{\alpha}$) between 0 and 1. This discounts the current background COMSR generated value and inflates the value of the marginal traffic. This method has the effect of forcing the submodules that make decisions based upon asset values (e.g. Reconstitution) to make those decisions in light of the now highly valued marginal traffic. This method could be a valuable source of information for answering our research questions.

$$\text{VALUE} = \alpha \sum_{p=R}^{FO} \frac{W_{p_c} N_{p_c}}{D_{p_c}} + \sum_{p=R}^{FO} \frac{W_{p_{BF}} N_{p_{BF}}}{D_{p_{BF}}} + \beta(\text{STATIC}) \tag{4.2}$$

R - Primary Rout A - Alternate Rout
C - COMSR BF - Marginal Traffic

It would also be possible to vary (β) from 1 to (∞) to conduct sensitivity analysis of the link for future planning missions or potential unplanned missions.

b. Non Operational Valuation

The value of each non operational link should also be captured at some interval, say hourly. To do this, one would take the links that fail the Availability Monte Carlo and the downtime that has been randomly drawn according to the Degradation Chapter. The Routing algorithm would continue to route traffic over the down links, however, the traffic would also be routed over the alternate route. Using Equation 4.3 , it would be possible to place a value on the down link.

$$\text{VALUE} = \alpha \sum_{p=R}^{FO} \frac{W^R_{p_c} N^R_{p_c}}{D^A_{p_c} - D^R_{p_c}} + \sum_{p=R}^{FO} \frac{W^R_{p_{BF}} N^R_{p_{BF}}}{D^A_{p_{BF}} - D^R_{p_{BF}}} + \beta(\text{STATIC}) \tag{4.3}$$

R - Primary Rout A - Alternate Rout
C - COMSR BF - Marginal Traffic

where ($D^A_{p_{BF}}$) is defined as the expected delay time of the alternate route at precedence "p" of the BF Interdiction traffic. This equation is sensitive to the added delay time of the alternate route. If there is not any added delay time then, obviously, the primary route was not important enough to place high on the reconstitution priority list.

V. RULE-BASED DECISION SUBMODULES

A. INTRODUCTION

The Air-Land Interdiction Model, as previously stated, is a research wargame and as such requires decision making to be consistent and reproducible. In order to achieve these lofty goals, the modules must make maximum use of man made rules and expert opinion to create "automated, closed loop" decision making algorithms that replace the "man in the loop". There are four rule based decision submodules in the CM; one, Degradation, has already been discussed. The other three will be discussed in this chapter. The methodology for developing each submodule is outlined in detail in the "Closed Loop Decision Making" section.

B. CLOSED LOOP DECISION MAKING

1. Selecting Communication Alternatives in a Combat Environment.

The primary objective of this section is to set forth and analyze the factors that allow a communications user to decide which of the available communications assets to use given that he has information that must be passed from himself to a distant receiver. The second objective is to translate these decision factors or attributes into a simple model.

The problem is to develop an automated Decision Submodule that "humanly" selects the communications mode (voice, record traffic, ETC.) and means (telephone, radio, ETC.). The key to the validity of this simulation is whether or not and to what extent the human thought process is actually reflected by the algorithm.

To accomplish this, an understanding of the job and skill level of the user and how he makes decisions under the pressure of combat is required. This section will illustrate this process for one user needline. The user will be the G-3 Operations officer for V Corps in Germany. The G-3 was chosen for study because he is a Combat Arms Officer in a high pressure job and has a wide array of communications available to pass messages. It is important to note that the concentration of this submodule should be with the processes of real combat and not the minutia of realism. The model must be robust enough to satisfy the communications selection decision of all users [Ref. 12].

a. Analysis of Decision Maker

A general model describing how the G3 Operations selects communication means can be seen in Figure 5.1 [Ref. 13]. The success or failure of the US Corps may very well rest on how well the G3 Ops planning staff directs the subordinate units to accomplish the Corp's flexible defense operations. An implicit requirement of this superior to subordinate directing is that at least one means of communication must be available. [Ref. 14]

The high intensity of the Corp's battle creates an enormous load and stress upon the G3. Other human variables that may effect our Decision Maker (DM) are his biological cycle, sleep loss, recent diet, recent successes or failures, and concerns for his family and many other variables [Ref. 15]. The G3 lacks the in depth understanding of the interconnectivity of the communication system that supports him. He is concerned with whether or not he can communicate, not how the communications works. His communication requirements are not always resolved in the most optimal or efficient manner especially for requirements for which there are no SOP's, contingency plans, advice of

co-workers, subordinates or communications officers to offer solutions. In these respects he is like 99% of the other users of communications on the battlefield. [Ref. 16]

b. Modelling of Decision Making

According to Cohen, March, and Olsen (1972), the G3 organization decision making can be characterized by ambiguity in technology, preferences, and participation. See Figure 5.1 [Ref. 13].

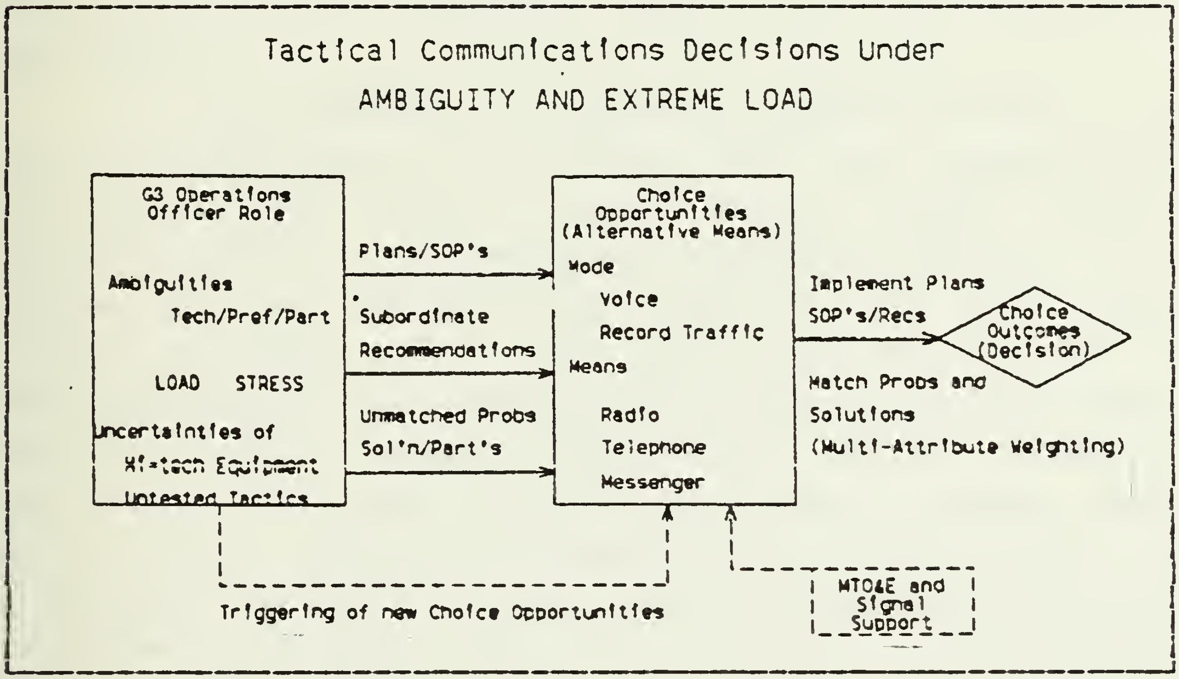


Figure 5.1 Tactical Communications Decision making

Ambiguity of Technology describes an organization's ignorance as to the options that are available to its DM's and the linkages between these alternatives and their likely consequences or outcomes. This difficulty is often aggravated by inexperience in particular roles, because all commanders and their subordinates rotate rapidly through new jobs.

Ambiguity of Preference contribute to the organized anarchy, by interfering with rankings of alternatives and their outcomes. Superior preferences in military operations are likely to be heterogeneous in the extreme.

Ambiguities of Participation are the result of participants who are part time, or shift their energies among decision situations within the organization, or across boundaries. In military operations ,fluidity of participation has two important causes: battle losses of key specialists or forces, and communication limitations that effectively isolate potential participation from decisions. [Ref. 13]

In reference to Figure 5.1 and Table XVIII, the Corps Standing Operating Procedures (SOP) and communication contingency plans require certain types, urgency levels, message lengths, or classification levels of messages to be transmitted over certain means [Ref. 14 and 16]. When several allowable means exist that appear to satisfy the requirement then a co-workers or subordinates' recommendation as to which means he had success with is generally implemented. The major dilemma occurs when it appears there are no SOP's, plans, or recommendations to rely upon. In these cases the G3 must match his unmatched communications requirement problems with any solution (communication means), that appear to have the highest probability of satisfying. When the user compares his alternative means in order to decide which to use, we have an example of Multi Attribute Decision Making (see Figure 5.2). It is important to remember that automating DM results in far more consistent decisions being made; therefore to truly simulate the DM a mild amount of inconsistency must be input. This is accomplished by rigorously incorporating expert human opinion of non-communications oriented personnel (ie. Combat Arms Officers) into MADMAN making sure to avoid the expert

opinion of communications personnel. MADMAN actually calculates the level of inconsistency for the experts' opinions. [Ref. 12]. and [Ref. 17]

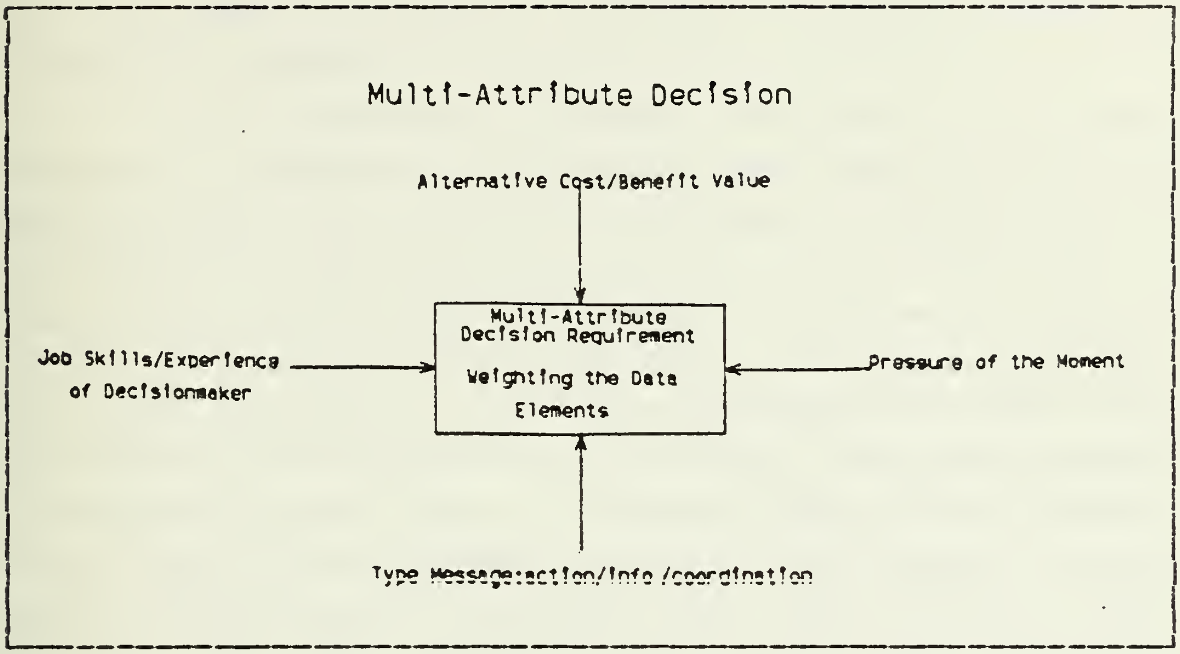

Multi-Attribute Decision
Alternative Cost/Benefit Value
Multi-Attribute Decision Requirement
Weighting the Data Elements
Job Skills/Experience of Decisionmaker
Pressure of the Moment
Type Message:action/info /coordination

Figure 5.2 Multi Attribute Decision Making

In MADMAN there is usually a countably small number of predetermined communications modes and means alternatives. The alternatives have associated with them several common attributes. A cost and benefit comparison of the attributes can be made and a final decision on which means to use can be reached. The decision as to which alternative to select is made with the help of pairwise attribute comparisons. The comparisons may involved explicit or implicit "expert opinion" tradeoffs. MADMAN is in short a decision aid to help maximize satisfaction with respect to more than one attribute.

MADMAN has many military applications, such as the evaluation and selection of personnel, strategy, weapon

systems, policy, facility locations, contracts; the evaluation of effectiveness; and expert judgement or group participation and analysis for selection, strategy, policy, etc.. Appendix C has a detailed explanation of MADMAN and a computer program developed by Marcello of MADMAN, as well as a practical example.

As a manager of scarce resources the G3 semi-consciously appraises the benefits and costs of all his actions. The depth of these appraisals depends upon the significance of the decision to be made. The G3 will seek to minimize the delay time of sending a message to the Air Defense Battalion S3 while attempting to minimize the relative costs of tying up the vital communications means being allocated to the communications problem. The data elements or attributes which link the decision maker to his communication selection are Urgency Required, Type Message, Message Length, Classification, Expected Delay Time of the "(I-1)th" message, and the communications alternatives available between the originator and the receiver. [Ref. 18] and [Ref. 19]

2. Results and Discussion of Automated "Closed Loop" Decision Model

The SOP and contingency plans are expected to predetermine solutions for most of the communications requirements. The remaining communications requirements will be solved using expert opinion to weight or scale the multiattribute data elements (listed under Subjective Filter in Table XVIII) in order to determine which communication alternatives would be selected.

In examining the results of the two runs made using the algorithm model in figures 5.1 and 5.2, it can be seen that automated DM has successfully been accomplished. In Table XVIII, the Objective Filter Data Elements give a

precise solution because the technical parameters matched the technical parameters of the SOP alternative. Intuition and the experience of the author confirm the selection as being correct; a five page, type written, classified, operations order would be transmitted using common user teletype circuits or Optical Character Recognition Equipment.

For ease of identification each user's communications is classified by a Type Communications Package, the type is strictly dependent upon the TO&E equipment and Common User System support authorized.

In Table XX the technical parameters could not be objectively filtered to provide an SOP solution. This Action Type message is by SOP transmitted using S/C Voice radio or Teletype; however, neither would satisfy the FLASH OVERRIDE urgency. The unsecure FM voice radio could not satisfy the urgency because time consuming manual encryption would have been required and the Lance BDE was out of range. All four alternatives could have satisfied classifications. All four could have satisfied message length although preparatory typing would have delayed transmission. Subjective filter elements were, therefore, implemented using expert opinion input into the MADMAN Program for multi attribute decision making (see Table XIX). [Ref. 17] Secure Telephone had the shortest expected delay time, lowest cost and highest benefit, and could motivate the receiver to the urgency of this information through the use of direct voice intonations and pitch.

The procedure outlined in Table XIX suggests some MADMAN input requirements that must be based upon C2 experts opinions in deriving the G3's decision.

TABLE XVIII

SOP or Contingency Decision Alternative Example

Data Elements	Explanation
Objective Filter	
Originator	Type A Comm Support Package G3 CORPS
Receiver	Type C Comm Support Package S3 ADA BDE
Urgency	Priority-5 page Operations Order for the counterattack air defense support beginning in 48 hours
Classification	Secure -secret classification
Message Length	1500 words
Type Message	Action
Subjective Filter	

Expected Delay Time for Alternatives, pressure of moment ,Cost and Benefit ,Experience of DM

Results: MTO&E Comm Available				Comm Alternatives	SOP Solution
Unsecure FM Voice	0	0	0		
Secure FM Voice	0	0	0	SECURE TELEPHONE	
Secure Telephone	0	1	0	SECURE TTY/OCRE	SEC TTY/OCRE
Secure TTY or OCRE	1	0	0	SECURE RATT	
Secure RATT	0	0	1		

Originator

Secure RATT
Secure Telephone
Secure TTY

Receiver

[Ref. 20 and 22]

TABLE XIX

Multi Attribute Decision Making Evaluation Example

1 . Define Alternatives

A1 = Unsecure FM Voice
A2 = Secure FM Voice
A3 = Secure telephone
A4 = Secure RATT

2 . Define Attributes

X1 = Delay Time of (N-1)st message
X2 = Skill required under pressure
X3 = ECCM capability
X4 = Voice Intonation
X5 = User experience with choice

3 . Construct a Pairwise Comparison of Attributes for weighting

	Cost X1	Cost X2	Benefit X3	Benefit X4	Benefit X5
X1	1	2	4	3	5
X2	1/2	1	2	1	3
X3	1/4	1/2	1	1	2
X4	1/3	1	1	1	2
X5	1/5	1/3	1/2	1/2	1

4 . Construct (A x X) matrix - Goal : Given the following alternatives and criteria evaluate the alternatives .

	X1	X2	X3	X4	X5
A1	low	high	v.low	v.high	high
A2	aver	aver	low	low	aver
A3	v.low	v.low	aver	v.high	v.high
A4	aver	v.low	v.low	low	low

5 . Assign Values for Interval Scale

	X1	X2	X3	X4	X5
A1	3	7	1	9	7
A2	5	5	3	5	5
A3	1	1	5	9	9
A4	5	2	3	1	3

6. The Scaled Values or S(j) are in Table XX

TABLE XX

Multi Attribute Decision Alternative Example

Data Elements	Explanation
Objective Filter	
Originator	Type A Comm Support Package G3 CORPS
Receiver	Type C Comm Support Package S3 Lance BDE
Urgency	Flash Override...Expect imminent enemy air attack to suppress nuclear delivery capability vicinity Fulda
Classification	Secure...Secret Classification
Message Length	13 words
Type Message	Action
Subjective Filter	

Expected Delay Time for Alternatives, pressure of moment ,Cost and Benefit ,Experience of DM

Results: MTO&E Comm Available					Comm Alternatives	S(j)	MADMAN Solution
Unsecure FM Voice	1	0	0	0	UNSECURE VOICE	.47	
Secure FM Voice	0	1	0	0	SECURE TELEPHONE	.99	SEC TELEPHONE
Secure Telephone	0	0	1	0	SECURE FM VOICE	.23	
Secure TTY / OCRE	0	0	0	0	SECURE RATT	.33	
Secure RATT	0	0	0	1			

Originator

Secure RATT
Secure Telephone
Secure Voice
Unsecure Voice

Receiver

[Ref. 20 and 21]

It is fascinating and encouraging to note the amount of research which is being accomplished in the arena of automated decision making. In referencing the model depicted in Figure 5.1, it can be seen that multi attribute decision making _can_ be a _source_ of _pre-determined solutions_ waiting for what had originally been an unmatched problem. Although definitive progress is being made, we are lagging well behind the Soviets in this field of automated "Cybernetics".

C. USER TO USER ROUTING DECISION

The User to User Decision Submodule (UUDS) as seen in Figure II, has three decisions to make. The Select Mode and Select Means decisions are rule-based decisions of expert players and SOP's. The Routing decision is based on network theory decision algorithm _Minimum Spanning Tree_.

The Select Mode decision draws upon the MTO&E database to determine the feasible modes available to both the originator (O) and the receiver (R). Once the communications modes are presented then the _urgency_ and _classification_ are considered to determine the optimal mode. If for some reason the primary selected mode is not available then the alternate modes are attempted in the order shown in Table XXI The message vector now has the parameters O, R, U, C, T, Mode (MD).[9]

The message vector now moves to the Select Means decision. Select Means draws upon the dedicated, organic communications available to O (MTO&E) and the inorganic communications provided by the Signal Corps or Host Nation. The Means are selected by determining the feasible and then

---

[9] These parameters are explained in detail in the Message Vector Section of Chapter 2.

TABLE XXI

Alternative Modes Selected

If primary mode fails then go to alternate.

Primary	Voice	RecTrf	Data	Fax	Mess
1st Alt	Rectrf	Fax	RecTrf	Mess	RecTrf
2nd Alt	Fax	Mess	Voice	Voice	Fax
3rd Alt	Mess	Voice	Mess		

the optimal Means available between O and R based upon U, C, MD selected, SOP's, and MADMAN.

The message vector progresses to the Select Route decision. The Select Route decision uses the Minimum Spanning Tree Algorithm to select the path that minimizes the number of nodes transitted. Both primary route availability and the secondary route and availability are added to the message vector and forwarded to the Availability Monte Carlo.

D. REROUTE SUBMODULE

The purpose of this submodule is to help answer the questions of what happens to the message vector if the critical path being transitted becomes impassable. Although the algorithm is still in its infancy, topics of importance and parameters are discussed in some detail. The requirement to rerout this message traffic stems from the reduced ability of a portion of the communication network to support the user in a timely manner. Based upon the availabilities, system outages would need to be scheduled events of the

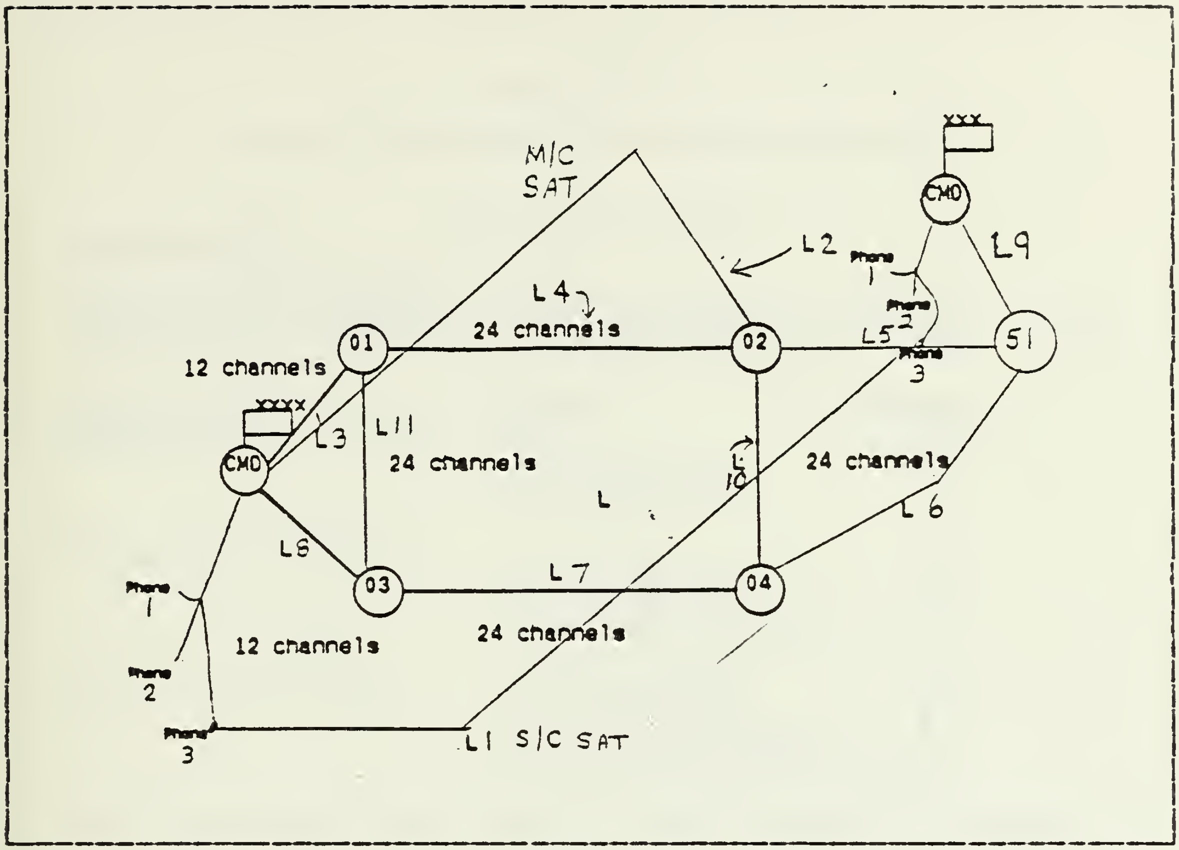


Figure 5.3 Minimum Spanning Tree Example

simulator. If the Monte Carlo failed for an 85% available system then the system would be down for (1-.85) x 24 hours = 3.6 hours = ($\underline{\lambda}$). An Exponential draw with mean 3.6 would be made to determine the actual down time and all submodules would be updated as seen in Figure 2.1 . The goal of Rerouting is to provide an alternate critical path which is still capable of satisfying the urgency precedence level and classification required for the message.

The Reroute Decision response is extremely dependent upon the mode and the means selected and the extent of degradation inflicted upon the network. Since the logic of Reroute varies with whether the means are single or multi-channel users the discussion will necessarily follow this natural break.

TABLE XXII

Minimum Spanning Tree Network Example

(See Figure 5.3)

Constraints:

Authorized Precedence Level
Immediate or Higher....S/C Satellite...1 node
Priority or higher...M/C Satellite...at least 2 nodes
Routine or higher... at least 3 nodes

Precedence	Route	#Nodes
Immediate or higher	L1	1 *
	L2-L5-L9	3 *
	L3-L4-L5-L9	4
	L8-L7-L6-L9	4
Priority or higher	L2-L5-L9	3 *
	L3-L4-L5-L9	4 *
	L8-L7-L6-L9	4
	L3-L4-L10-L6-L9	5
Routine or higher	L3-L4-L5-L9	4 *
	L8-L7-L6-L9	4 *
	L3-L4-L10-L6-L9	5
	L8-L11-L4-L5-L9	5
	L3-L11-L7-L10-L5-L9	6

*Minimum Node Routes become message vector parameter

1. Single Channel

The single channel means of communication is generally a radio dedicated or sole owned by its user. It can be either a Push-to-Talk voice, data, or teletype optimized transceiver. These types of radios are used primarily while mobile. They are line of sight and are sensitive to ECM especially when used for over two minutes at a time. We assume that if a user attempts to use a net radio and finds the net (frequency) congested with other users, he will continue to attempt to use this means while fully realizing that he must wait to get his turn on the frequency. If however, the frequency is being successfully jammed (R F Interdiction) then the user has several choices. If the

radio is his only means of communication, then he may continue to try to break through the jamming or he can change to an alternate frequency. Net control is difficult under jamming conditions. The net control station attempts to inform other users to change frequency to the pre-established alternate. If it is impossible to reestablish the net then he may just send a messenger. If this radio net is not the only means available then the user will likely decide to change to a means that is less susceptible to jamming and direction finding.

2. Multichannel

Multichannel means of communications are generally far more robust in an ECM environment then single channel radios. Whether the multichannel radios are line of sight or over the horizon, whether they are dedicated as in the the Air Defense arena , or common user as provided by the Signal Corps, the radios are integrated into a network grid which provides redundant paths between nodes. At the nodes are switches which either automatically or manually reroute traffic from nonavailable links to available links. The additional time of reroute is usually not critical to the user unless the alternate route has been congested. Only if it appears that the alternate link will not satisfy the urgency precedence levels required will the user think of selecting another means of communication. An example is referred to in Table XXIII .

If the message vector was given the Microwave route and this failed at the the Monte Carlo, the alternate route of AM Single Side Band would then be Monte Carloed; if it passed then the accumulated time would be 25 seconds for the MW attempt and 60 seconds for the AM route; a total of 85 seconds.

TABLE XXIII

Example

Network Entities	Availability	Nodes	E(Delay Time)
Microwave	.95	2	25 seconds
UHF	.85	3	25 seconds
AM SSB Voice	.92	2	60 seconds
Combined UHF & MW	.78	2	35 seconds

* ROUTES SELECTED:
1. microwave
2. AM SSB
3. UHF
4. Combined System

* Selection based on fewest number of nodes (highest availability)

If an alternative route for multichannel or an alternative means for single channel was decided upon then the appropriate availability would again be Monte Carloed with delay time added. An important product of the Rerout Module is the CGVS evaluation of non-operational links. The CGVS determines the lost value of messages over down links and reports this to the Reconstitution Submodule. This lost value is critical to the resource allocation decision in restoring down links.

E. RECONSTITUTION SUBMODULE

The purpose of this submodule is to correct deficiencies of the communications system in supporting its users. Available and reliable communication is a critical necessity. This submodule is important to the overall Communications Module, however, the algorithm is still in its very early stages. Crucial issues and parameters are discussed which allows a smoother transition in future research efforts.

If communications is lost within any important part of the network, allocation decisions must be made by the system planners and controllers to reconstitute stricken areas. The Reconstitution Module (RM), depicted in Figure 2.1, will receive the type degradation and the value of the link up to the current point in time. The module will internally allocate resources to correct the source of degradation and return to the communication degradation module the expected time to restoration of link capability and the upgraded availability. The Reconstitution submodule will also notify the Rerouting Submodule as to how long it will have to reroute traffic around the degraded link.

The RM will look at the severity of the damage and assign a priority for reconstitution. It will decide based on availability and location of reconstitution equipment and the cause of degradation if and when the link will be available for further use.

VI. SUMMARY AND CONCLUSIONS

The Corps Communications Module described in this thesis uses a variety of academic and real world phenomenon to simulate the flow of communications between battlefield users and to evaluate communications assets' worth. Academically, the CM uses the properties developed by A.K. Erlang's Telephone Traffic Theory and related works to establish the need for and the use of (λ), the message arrival rate, and (μ), the message service rate. If traffic summaries (λ's, μ's) are available for each arc (link) then blocking probabilities and mean delay times may be derived. Communications assets values are a function of these delay times encountered over the links. Real world phenomenon such as environmental occurrences, Red Force interdiction, and Blue Force congestion drastically effect the links that are available to pass message traffic. These degradation forms are critical players in a communications simulation and are discussed in detail. The Poisson principles of Decomposition and Superposition allow for easy handling of diverted traffic loads (additivity of λ's) and in analyzing multiserver queues in a simple fashion.

The Corps Communications Module also develops a myriad of decision making techniques to allocate resources to areas in need. The Communication Generalized Value System provides a methodology for determining hardware asset value which in turn can be used for allocation of resources that maintain communications. MADMAN provides a methodology and a means to make decisions that are not backed up by hard numbers; MADMAN is the "fuzzy" area decision making tool. MADMAN can be extensively used for developing pre-determined solutions to problems that have not yet occurred; in other words with

the help of expert opinion, MADMAN can be used to "close the loop" on simulating man made decisions in an automated "man-less" algorithm. Standing Operating Procedures are the most common pre-determined source of solutions to problems and should be used as the rule rather than the exception. SOP's provide decision alternatives in the "well structured and defined" areas.

In conclusion, the CM submodules are presented at various levels of mature development. These algorithms do provide an excellent start point for a programmer to further develop the CM into a working module. The analysis of derived CGVS values and the message vector audit trails can shed light into the previously foreboding research question areas of communications systems supporting functional areas in a combat environment.

APPENDIX A

VARIABLE RESOLUTION DIAGRAMS FOR COMMUNICATION MODULE

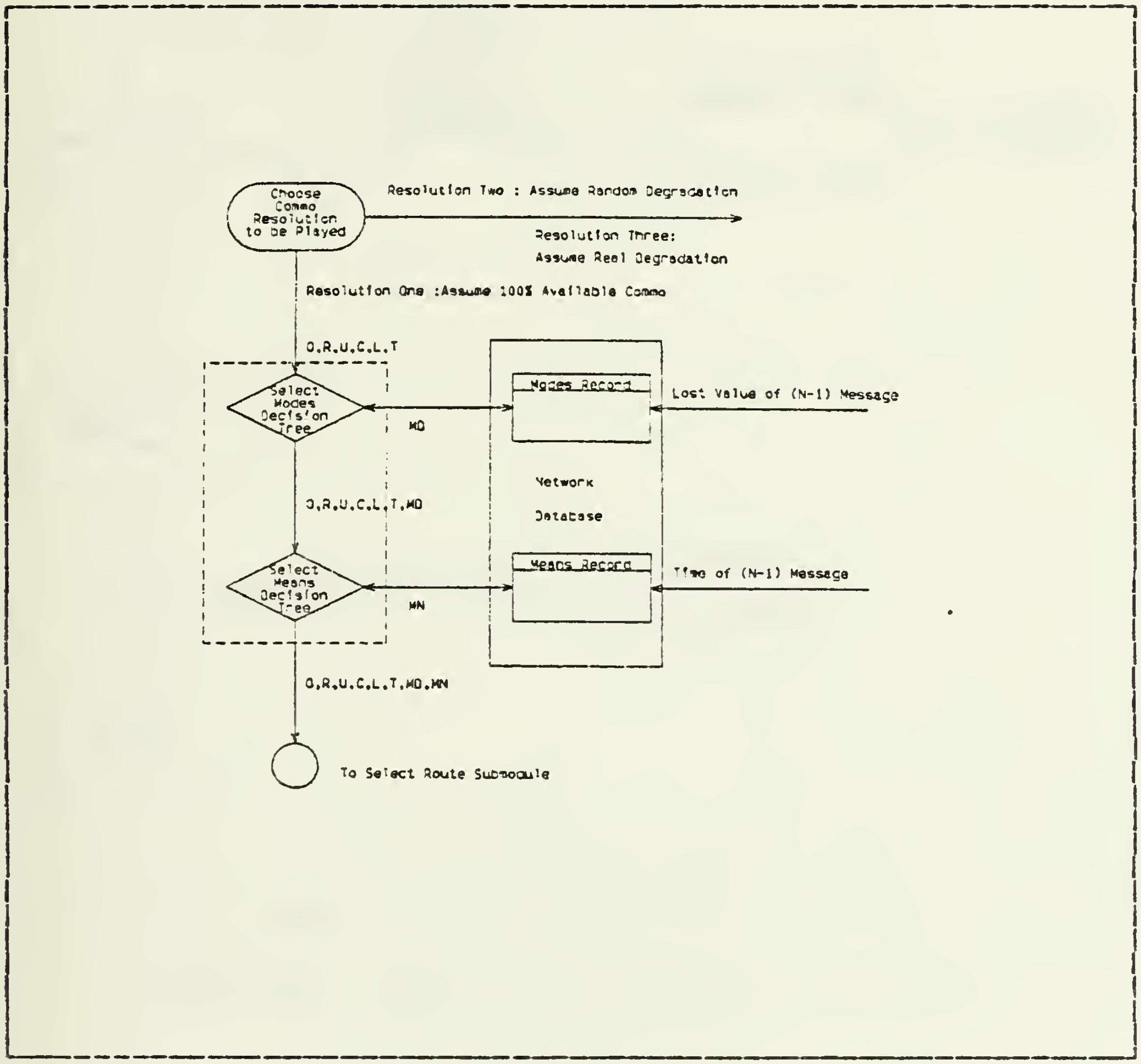

Choose Commo Resolution to be Played
Resolution Two : Assume Random Degradation
Resolution Three:
Assume Real Degradation
Resolution One :Assume 100% Available Commo
O,R,U,C,L,T
Select Modes Decision Tree
MD
O,R,U,C,L,T,MD
Select Means Decision Tree
MN
O,R,U,C,L,T,MD,MN
To Select Route Submodule
Modes Record
Network
Database
Means Record
Lost Value of (N-1) Message
Time of (N-1) Message

Figure A.1 Resolution Level One

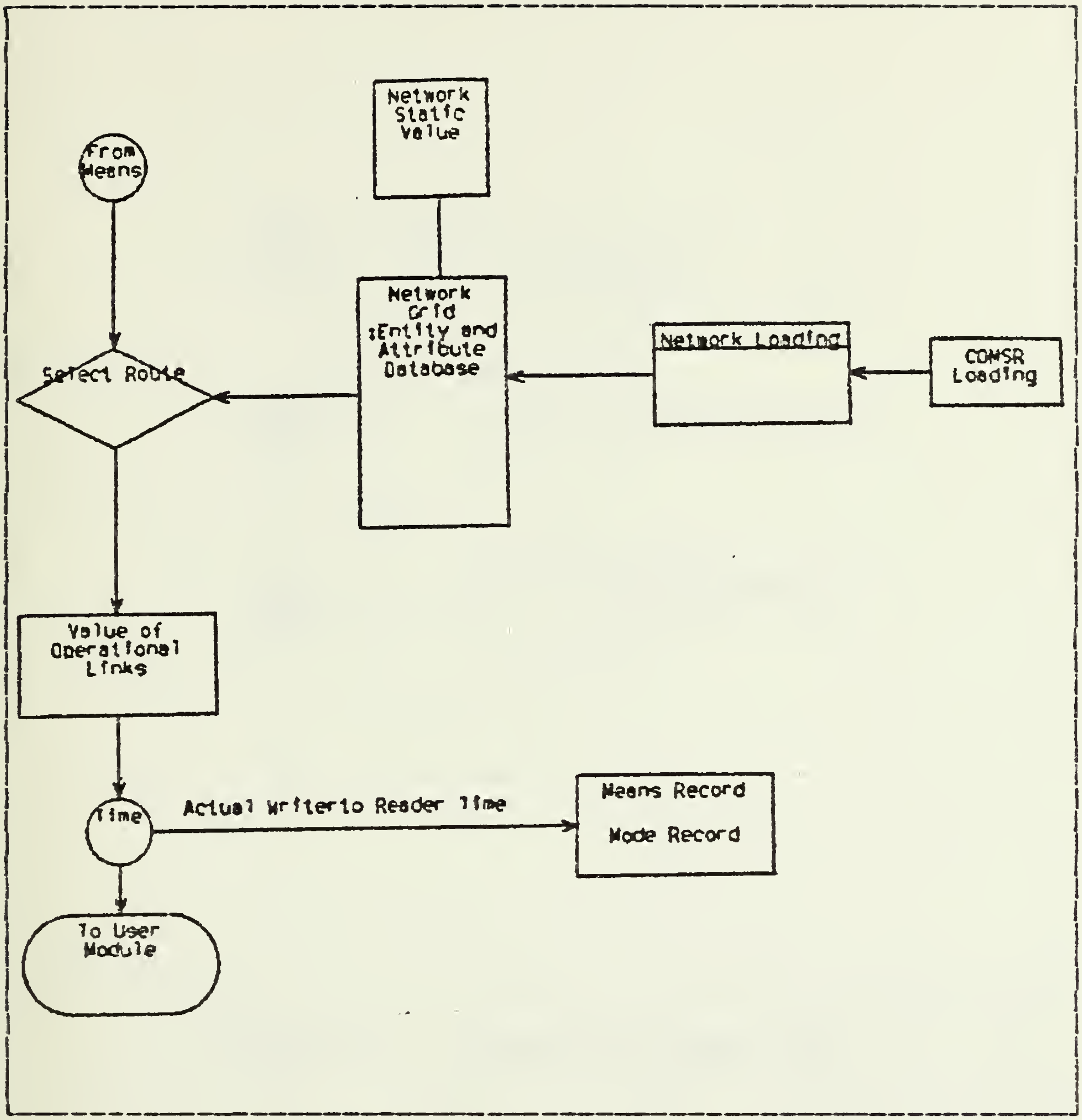


Figure A.2 Resolution Level One (continued)

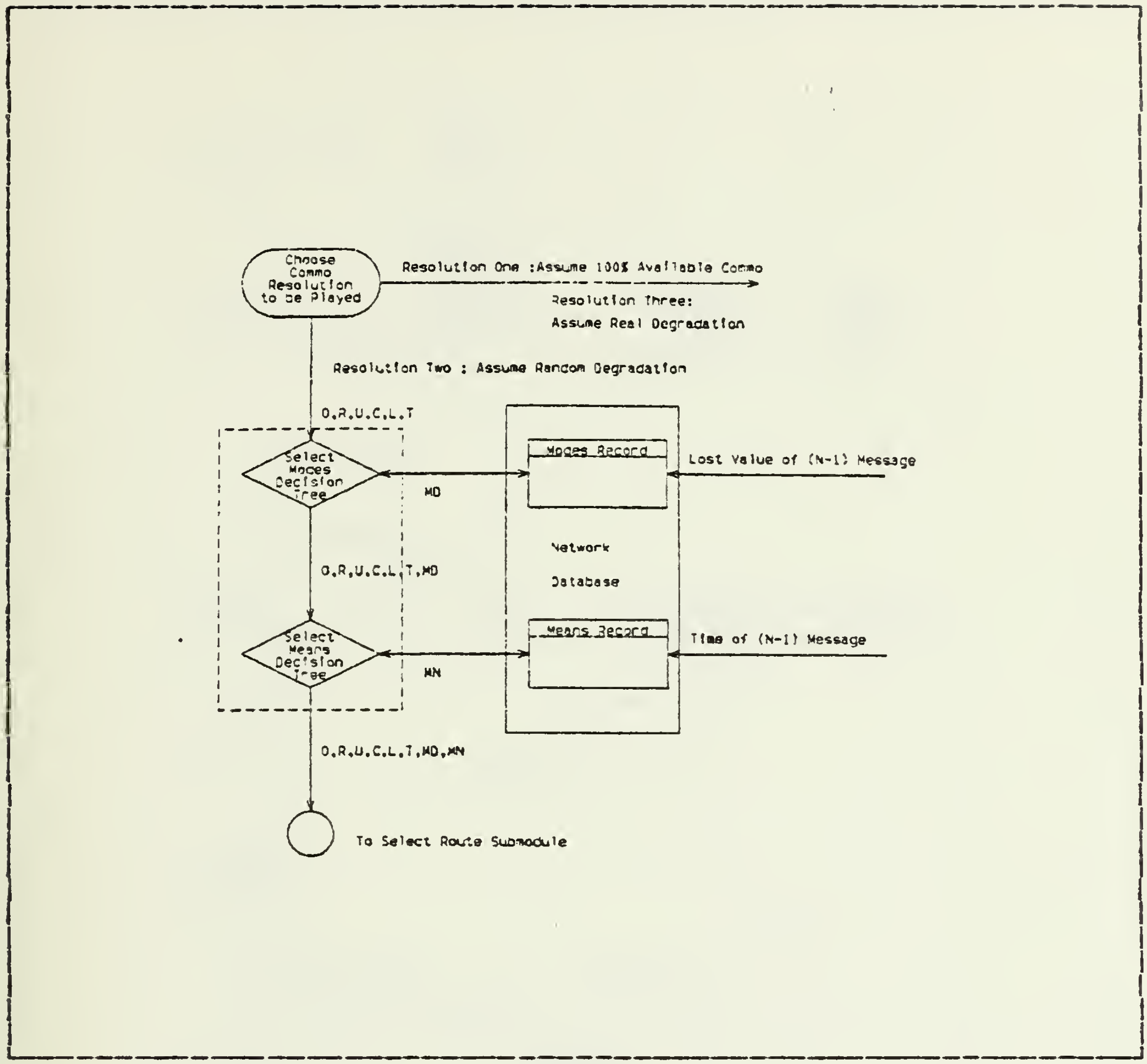

Choose Commo Resolution to be Played
Resolution One :Assume 100% Available Commo
Resolution Three:
Assume Real Degradation
Resolution Two : Assume Random Degradation
O,R,U,C,L,T
Select Modes Decision Tree
MD
Modes Record
Lost Value of (N-1) Message
Network
Database
O,R,U,C,L,T,MD
Means Record
Time of (N-1) Message
Select Means Decision Tree
MN
O,R,U,C,L,T,MD,MN
To Select Route Submodule

Figure A.3 Resolution Level Two

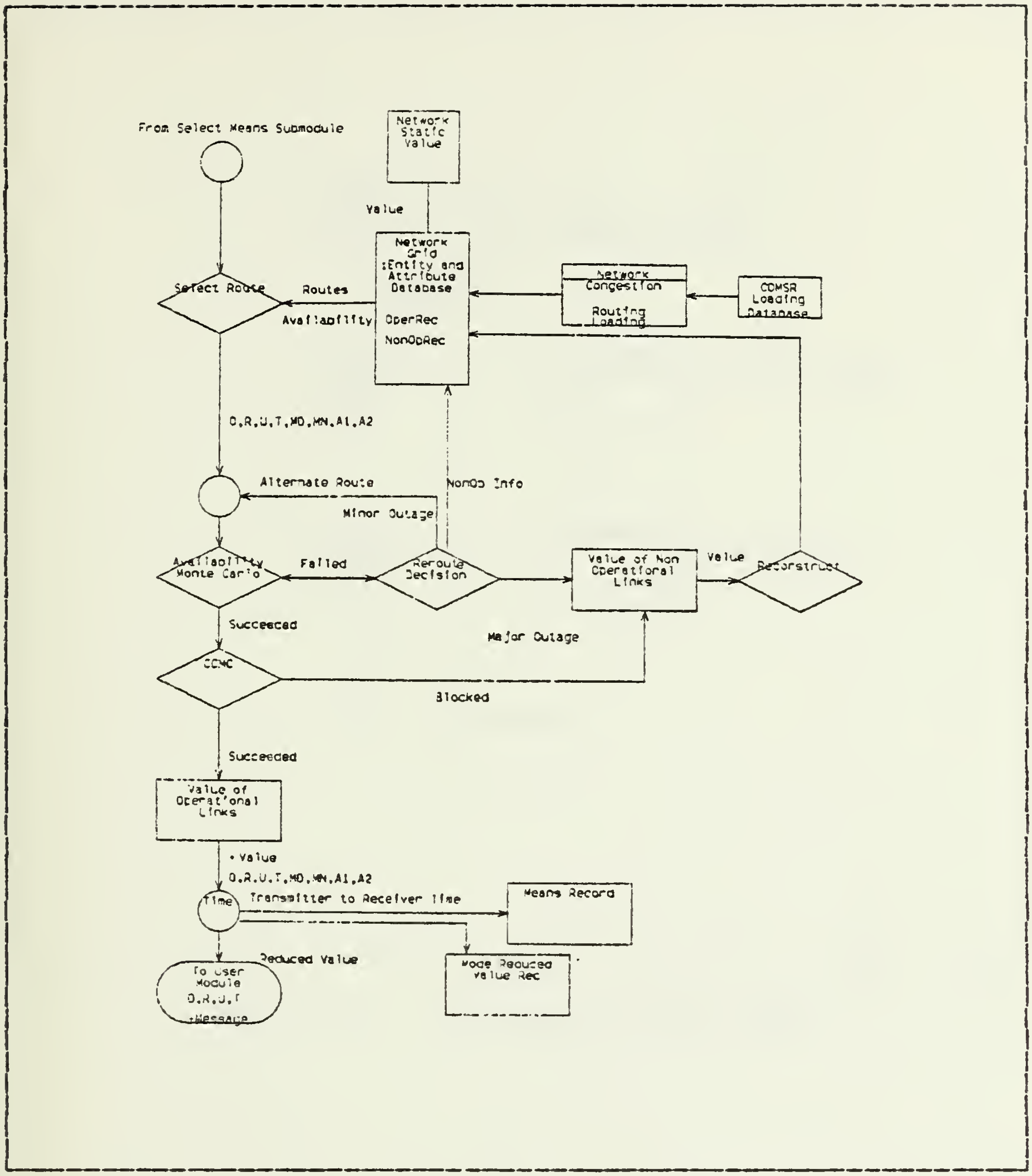


Figure A.4 Resolution Level Two (continued)

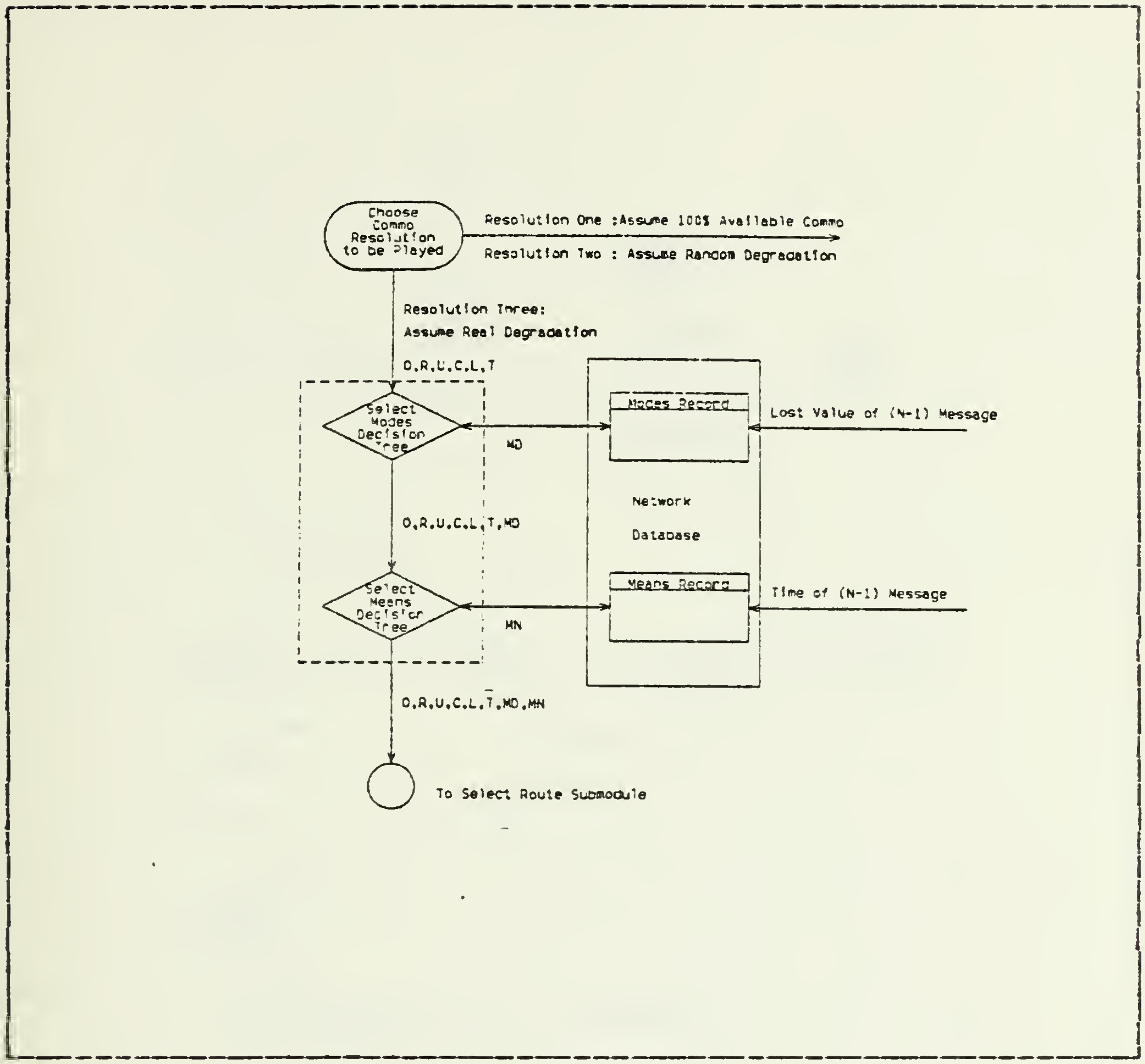

Choose Commo Resolution to be Played
Resolution One :Assume 100% Available Commo
Resolution Two : Assume Random Degradation
Resolution Three:
Assume Real Degradation
O,R,U,C,L,T
Select Modes Decision Tree
MD
Modes Record
Lost Value of (N-1) Message
Network
Database
O,R,U,C,L,T,MD
Select Means Decision Tree
MN
Means Record
Time of (N-1) Message
O,R,U,C,L,$\bar{T}$,MD,MN
To Select Route Submodule

Figure A.5 Resolution Level Three

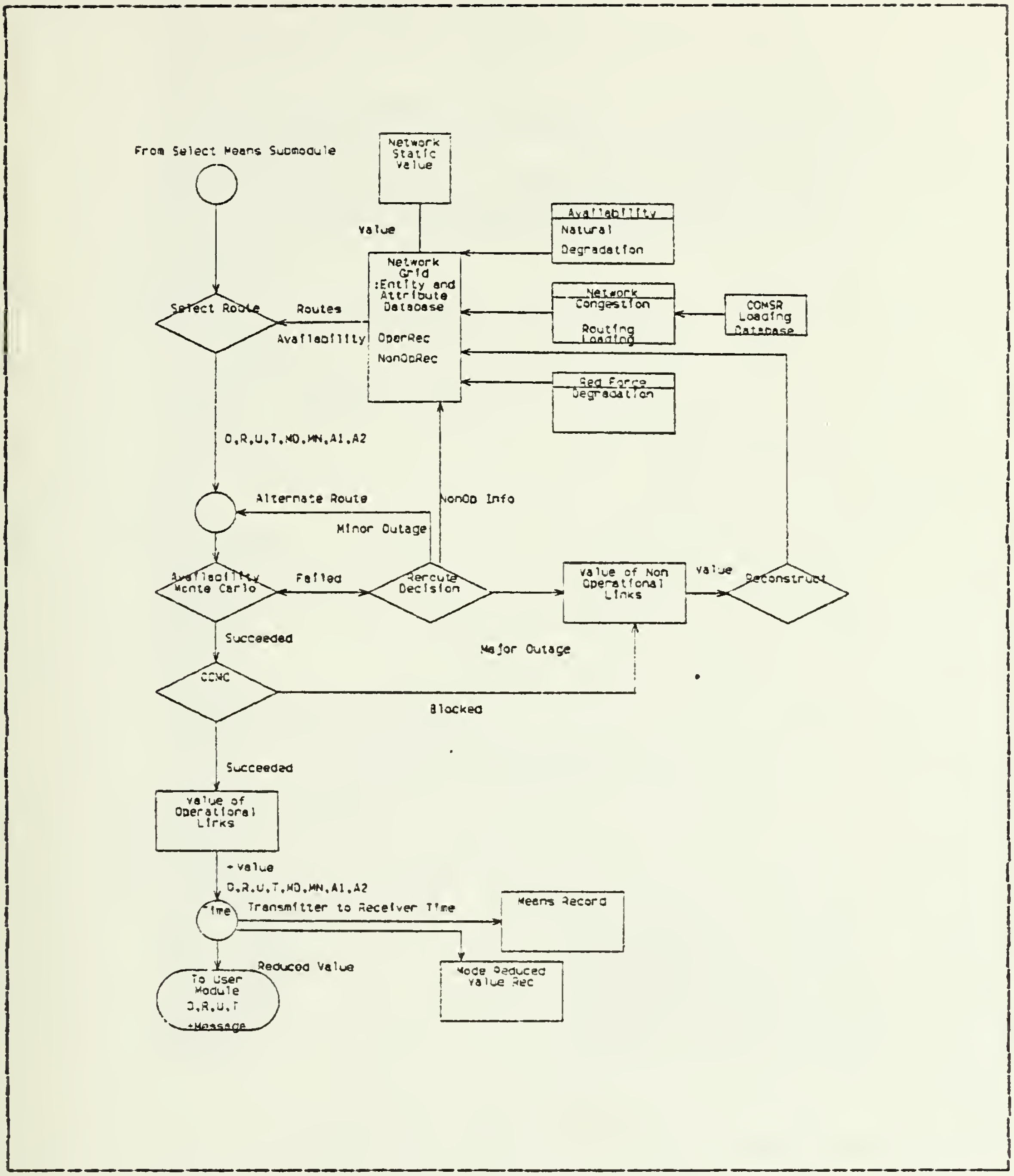


Figure A.6 Resolution Level Three (continued)

```
      INTEGER SN(31), EN(31), UB, ARC(30), SCHDUL(30), NODE(60)
      REAL LENGTH(31)
      DATA YES/'Y'/
      UB=30
    1 FORMAT(' MINIMAL SPANNING TREE'//' ENTER ARCS AS FOLLOWS:'//
     1' STARTING NODE, ENDING NODE, DISTANCE'//' STOP INPUT BY TYPING:0,
     20,0'//)
    2 FORMAT('+ARC ',I2,':'$)
    4 FORMAT(' DONE'//' THE M. S. T. CONSISTS OF THE FOLLOWING ARCS:'/)
    6 FORMAT(/' DO YOU WISH TO DO ANOTHER PROBLEM?:'$)
    7 FORMAT(' SORRY, BUT THE PROGRAM CAN CURRENTLY ACCEPT AT MOST ',I2,
     1' ARCS.'//' GOODBYE')
    8 FORMAT(3G)
    9 FORMAT(A1)
   21 FORMAT(' ARC ',I2,'(',I2,',',I2,')')
   10 WRITE(4,1)
      UB=UB+1
      DO 11 N=1,UB
      WRITE(4,2) N
      READ(4,8) SN(N), EN(N), LENGTH(N)
      IF(SN(N)) 12,12,11
   11 CONTINUE
      UB=UB-1
      WRITE(4,7) UB
      STOP
   12 N=N-1
      UB=UB-1
   13 DO 14 I=1,N
   14 SCHDUL(I)=0
      UB=UB*2
      DO 24  J=1,UB
   24 NODE(J)=0
      UB=UB/2
      NODE(1)=1
      L=0
   15 MINARC=0
      DO 16 I=1,N
      IF(SCHDUL(I).EQ.1) GO TO 16
      J=SN(I)
      K=EN(I)
      IF(NODE(J).EQ.1.XOR.NODE(K).EQ.1) GO TO 18
      GO TO 16
   18 IF(MINARC) 19,19,20
   19 MINARC=I
      GO TO 16
   20 IF(LENGTH(MINARC).GT.LENGTH(I)) GO TO 19
   16 CONTINUE
      IF(MINARC.EQ.0) GO TO 23             23 WRITE(4,4)
      L=L+1                                   DO 22 II=1,L
      ARC(L)=MINARC                           I=ARC(II)
      SCHDUL(MINARC)=1                     22 WRITE(4,21) I, SN(I), EN(I)
      J=SN(MINARC)                            WRITE(4,6)
      K=EN(MINARC)                            READ(4,9) ANSWER
      NODE(J)=1                               IF(ANSWER.EQ.YES) GO TO 10
      NODE(K)=1                               STOP
      GO TO 15                                END
```

Figure A.7 Minimum Spanning Tree Program

APPENDIX B

GLOSSARY OF TERMS AND ACRONYMS

A. TERMS

A working understanding of the entities and attributes of the communications network is essential to the programmer and will be described in detail in the following appendix . Entity. . . An end item or piece of hardware that possesses attributes which characterize the communications link. Example: An AN/TRC 138 is a line of sight , multichannel radio which ties two Corps Area Signal nodes together. The arc or airwaves between the two nodes carry secure voice, record traffic and data. Attributes. . . A characteristic such as reliability , comm security, frequency, ETC. are key to describing entities such as links and link hardware.

Cable. . . Intrasite cable is the 26 pair cable strung between the communications vans within a signal node. Significant power losses occur along this cable therefore the maximum length is 1500 feet, this restriction limits the dispersion of comm vans, thereby increasing vulnerability to air and artillery and ECM interdiction efforts. Intersite cable or PCM (CX11230) provides multichannel access to large users within a 40 mile radius. Vulnerability to interdiction is very small. Intersite cable systems are often used to separate Command Signal nodes from the headquarters they are supporting.

Data. . . Message information passed between I/O devices and computers, or computer to computer. It is capable of extremely fast transfer of information. Circuits supporting data systems must be specially conditioned or optimized for data transmission. Voice circuits perform poorly when attempting to pass data traffic.

Direction Finding. . . An ECM capability which locates electronic emission sources. It is a passive collector and therefore it is very difficult to detect. They are the eyes for jammers, air, and artillery interdiction fires. The threat may be reduced by the prudent use of emission terrain masking, use of lower power settings, short messages ETC. Airborne direction finders must fly parallel to the FEBA at slow speeds and therefore are vulnerable to ground or air attack.

Expected Delay Time. . . The expected value or mean delay time a message experiences as a result of net congestion, terminal congestion, enemy interdiction efforts, or normal transit time. This is the key parameter which the commo value system and therefore the entire commo network asset value is judged.

Facsimile. . . Message transmission device which is capable of actually passing true copies of hand written notes, maps, pictures , ETC. .

Frequency. . . Wavelength to which radios are tuned to transmit and receive electronic messages. Airwaves "wavelength" vary in vulnerability with changes in atmospheric conditions, jam-ability, maximum distance emissions can be detected, ETC..

Jamming. . . An ECM capability which put noise on communications links and reduces those links reliability. Jammers are frequency, directional, and power output dependent and are highly vulnerable to interdiction because of their unique electronic signature.

Line of Sight. . . (LOS) Attribute required because radio waves bend very little around blocking terrain or buildings.

Link. . . Also referred to as an arc or a branch of a communication network. They tie nodal switching points and users together. SEE: entity , attribute. Message. . . A

discrete block of information passed from the initiator to the receiver, it may have many attributes most important of which are its urgency and classification.

The load or subscriber demand is defined as the average number of calls offered times the average call duration .

Node. . . A junction point in a communications network. Access to and from the network may be gained at the node. Example: the Corps Area Signal nodes provides switching facilities for messages going through the node as well as input and output facilities for terminal users.

Nonsecure. . . Message information passed in the clear or unencrypted mode. By 1986 it will be found only at Armor and Infantry company and platoon nets. Manual encryption of sensitive information will still be possible at this level.

Over the Horizon. . . (OTH) Attribute of type radio that use the troposphere, ionosphere, or satellites to reflect radio waves over the radios' horizon. The OTH radios give the user a "skip echelon" capability to bypass damaged or destroyed commo systems. OTH still requires a clear window along the directed azimuth of the system but vulnerability is reduced because OTH radios do

Quality of service is characterized by the probability that a call offered during the typical busy hour will be blocked .

Radio. . . An electronic means of passing messages from one user to another. Radios have either single channel or multichannel capability depending upon what the user demand requires to support his needs. The range of propagation varies dependent upon power output, terrain, frequency, friendly interference and enemy interdiction.

Record Traffic. . . Electronic passage of information which produces hard copy record of message. Example: Teletype or facsimile. Record traffic is capable of transmission speeds faster than voice but slower than data.

Record traffic is generally better in a high ECM environment than voice because information is binary pulsed rather than voice modulated (frequency or amplitude modulation) requiring less transmit time, less exposure to possible DF.

Rejecting a call means giving the subscriber a busy signal , even if the number he is calling is not busy . Alternatively , the call is rerouted via some other trunk , or it is held until a line becomes available and thus suffers a delay . In none of these three cases does the exchange handle the call immediately , and regardless of its future fate the call is said to be blocked . It is actually the exchange that is blocked , unable to let the traffic flow through it; the calls are lost to the exchange if rejected or rerouted , and held if delayed , but both lost and held calls are often denoted by the common nameof blocked calls .

Switch. . . Either circuit (telephone) or message (Record Traffic) switches. Switches are responsible for routing , rerouting, storing and frowarding of messages. The switch routing logic determines orientation or direction of traffic and flow capacity of the node. It limits the traffic directed down any on link based upon the link flow capacity.

Terminal Equipment. . . Actual hardware employed by the user to access the commo network. Example: telephone, visual display, optical character reader, facsimile, teletypewriter , ETC. .

Voice. . . Message traffic employing the voice frequencies of 0-3000 hertz such as a single channel voice optimized radio and the common user telephone system.

B. ACRONYMS

A1...primary route availability

A2...alternate route availability

AD...Air Defense

ALIM...Air-Land Interdiction Model

Ao...Operational Availability

ASC...Area Signal Center

BF...Blue Force

BFI...Blue Force Interdiction

C3I...Command, Control, Communications, and Intelligence

CCMC...Circuit Connect Monte Carlo

CGVS...Communications Generalized Value System

CM...Corps Communications Module

COMINT...Communications Intelligence

COMMZ...Communications Zone

COMSR...Communications Support Requirements Database

D...mean delay time

EAD...Echelon Above Division

ECM...Electronic Countermeasures

ECCM...Electronic Counter-countermeasures

EMP...Electro-magnetic Pulse

FEBA...Forward Edge of Battle Area

FLOT...Forward Line of Troops

H/P...Hawk or Patriot Air Defense Unit

INTACS...Integrated Tactical Communications System

LOS...Line of Sight

MADMAN...Multi Attribute Decision Making Algorithm

MC...Monte Carlo

M/C...Multi-channel

MD...Modes

MN...Means

MTBF...Mean Time between Failure

MTTR...Mean Time to Repair

Non-op...Non-operational

O...Originator

Op...Operational

ORSA...Operations Research and Systems Analysis

R...Receiver

RDF...Radio Direction Finding

REC...Radio Electronic Combat

RF...Red Force

RFI...Red Force Interdiction

RFIM...Red Force Interdiction Module

RM...Reconstitution Submodule

S/C...Single Channel

SOP...Standing Operating Order

T...Elapsed Time

TRADOC...Training And Doctrine Command

TTT...Telephone Traffic Theory

U...urgency or precedence level

UW...Unconventional Warfare

V Corps...5th U.S. Army Corps, located near Fulda Salient West Germany

TO&E...Table of Organization and Equipment

Lambda (λ) ...message arrival rate

MU (μ) ...message service rate

RHO (ρ) ...traffic intensity, utilization factor, or Erlang

APPENDIX C

BRIEFING ON MULTI-ATTRIBUTE DECISION MAKING

MADMAN

MADM can be used to evaluate the effectiveness and therefore the utility value that similar mission communications systems contribute to the overall communications network. The following procedure outlines the MADM input requirements that must be based upon communications and C2 experts opinions.

TABLE XXIV

Multi Attribute Decision Making Evaluation Example

1 . Define Alternatives .

eg. A1=satellite ground station
A2 = HF radio
A3 = microwave radio
A4 = FM radios
A5 = Mobile Subscriber Terminal

2 . Define Attributes

X1 = Channel Capacity
X2 = Skip Echelon Capability
X3 = Survivability
X4 = Reliability
X5 = Cost

TABLE XXV

MADMAN Evaluation

3 . Construct a Pairwise Comparison of Attributes for weighting

	Benefit X1	Benefit X2	Benefit X3	Benefit X4	Cost X5
X1	1	2	2	5	1
X2	1/2	1	3	3	1/2
X3	1/2	1/3	1	1	3
X4	1/5	1/3	1	1	2
X5	1	2	1/3	1/2	1

4 . Construct (A x X) matrix - Goal : Given the following alternatives and criteria evaluate the alternatives .

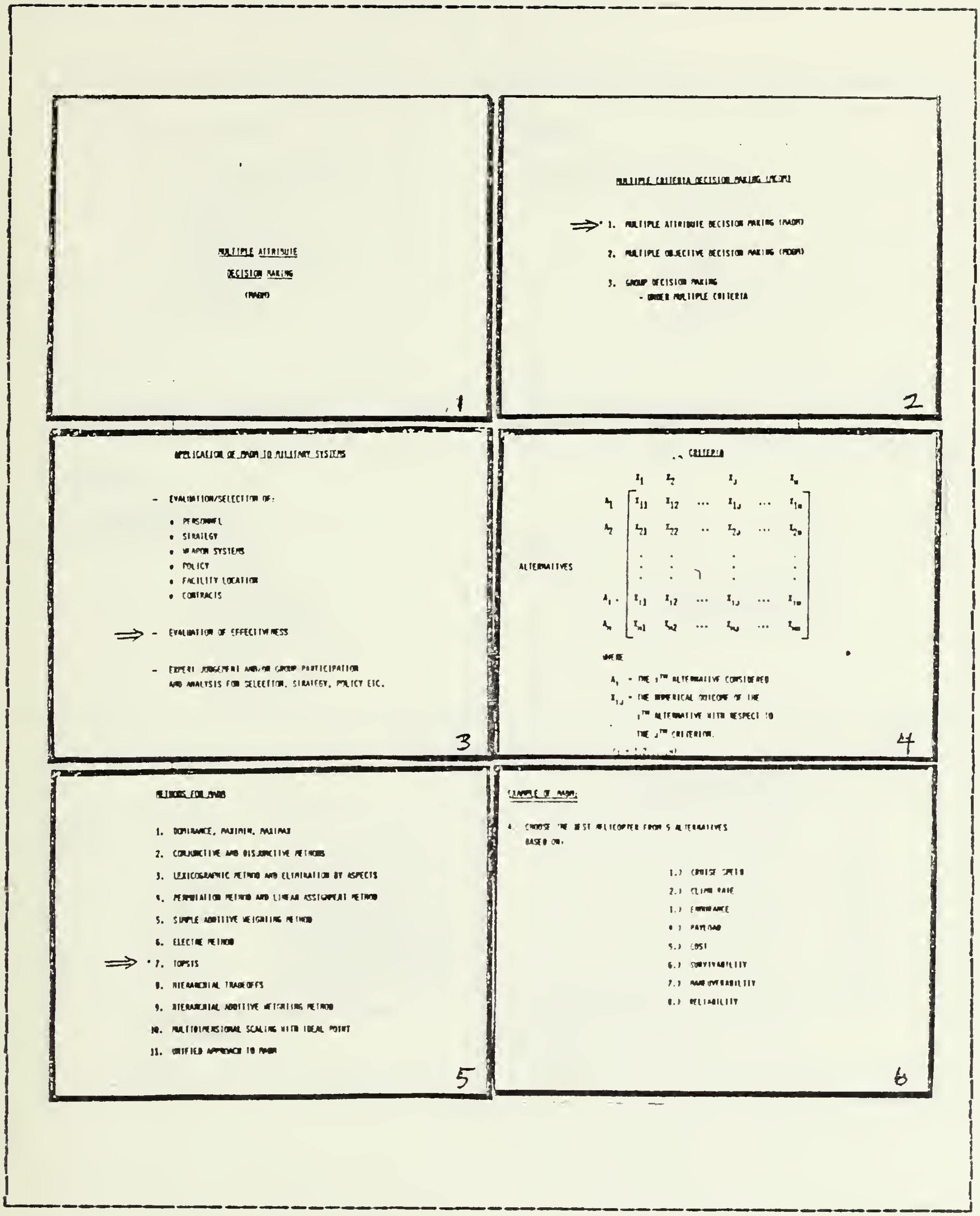
	X1	X2	X3	X4	X5
A1	High	Excellent	Very Good	Good	High
A2	Low	Excellent	Poor	Average	Low
A3	High	Poor	Good	Excellent	Average
A4	Low	Poor	Fair	Very Good	Very Low
A5	Low	Fair	Good	Very Good	Low

5 . Assign Values for Interval Scale

	X1	X2	X3	X4	X5
A1	9	10	8	7	1
A2	2	10	2	4	7
A3	9	3	7	9	4
A4	1	2	4	8	9
A5	3	4	7	8	6

6 . Run TOPSIS

A . Normal Decision Matrix
B . Weighted Normal Decision Matrix
C . Take Relative Closeness C = (C1 , C2 , . . . C5) x 100) = Utility Value



MULTIPLE ATTRIBUTE

DECISION MAKING

(MADM)

1

MULTIPLE CRITERIA DECISION MAKING (MCDM)

⇒ 1. MULTIPLE ATTRIBUTE DECISION MAKING (MADM)

2. MULTIPLE OBJECTIVE DECISION MAKING (MODM)

3. GROUP DECISION MAKING
   - UNDER MULTIPLE CRITERIA

2

APPLICATION OF MADM TO MILITARY SYSTEMS

- EVALUATION/SELECTION OF:
  - PERSONNEL
  - STRATEGY
  - WEAPON SYSTEMS
  - POLICY
  - FACILITY LOCATION
  - CONTRACTS

⇒ - EVALUATION OF EFFECTIVENESS

- EXPERT JUDGEMENT AND/OR GROUP PARTICIPATION AND ANALYSIS FOR SELECTION, STRATEGY, POLICY ETC.

3

CRITERIA

ALTERNATIVES

$$\begin{array}{c|cccccc|}
 & X_1 & X_2 & & X_j & & X_n \\
A_1 & x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\
A_2 & x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\
 & \vdots & \vdots & & \vdots & & \vdots \\
A_i & x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\
A_n & x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nn}
\end{array}$$

WHERE

A_i = THE i^{TH} ALTERNATIVE CONSIDERED

X_{ij} = THE NUMERICAL OUTCOME OF THE i^{TH} ALTERNATIVE WITH RESPECT TO THE j^{TH} CRITERION.

$(i = 1, 2, \ldots, n)$

4

METHODS FOR MADM

1. DOMINANCE, MAXIMIN, MAXIMAX
2. CONJUNCTIVE AND DISJUNCTIVE METHODS
3. LEXICOGRAPHIC METHOD AND ELIMINATION BY ASPECTS
4. PERMUTATION METHOD AND LINEAR ASSIGNMENT METHOD
5. SIMPLE ADDITIVE WEIGHTING METHOD
6. ELECTRE METHOD
7. TOPSIS ⇐
8. HIERARCHICAL TRADEOFFS
9. HIERARCHICAL ADDITIVE WEIGHTING METHOD
10. MULTIDIMENSIONAL SCALING WITH IDEAL POINT
11. UNIFIED APPROACH TO MADM

5

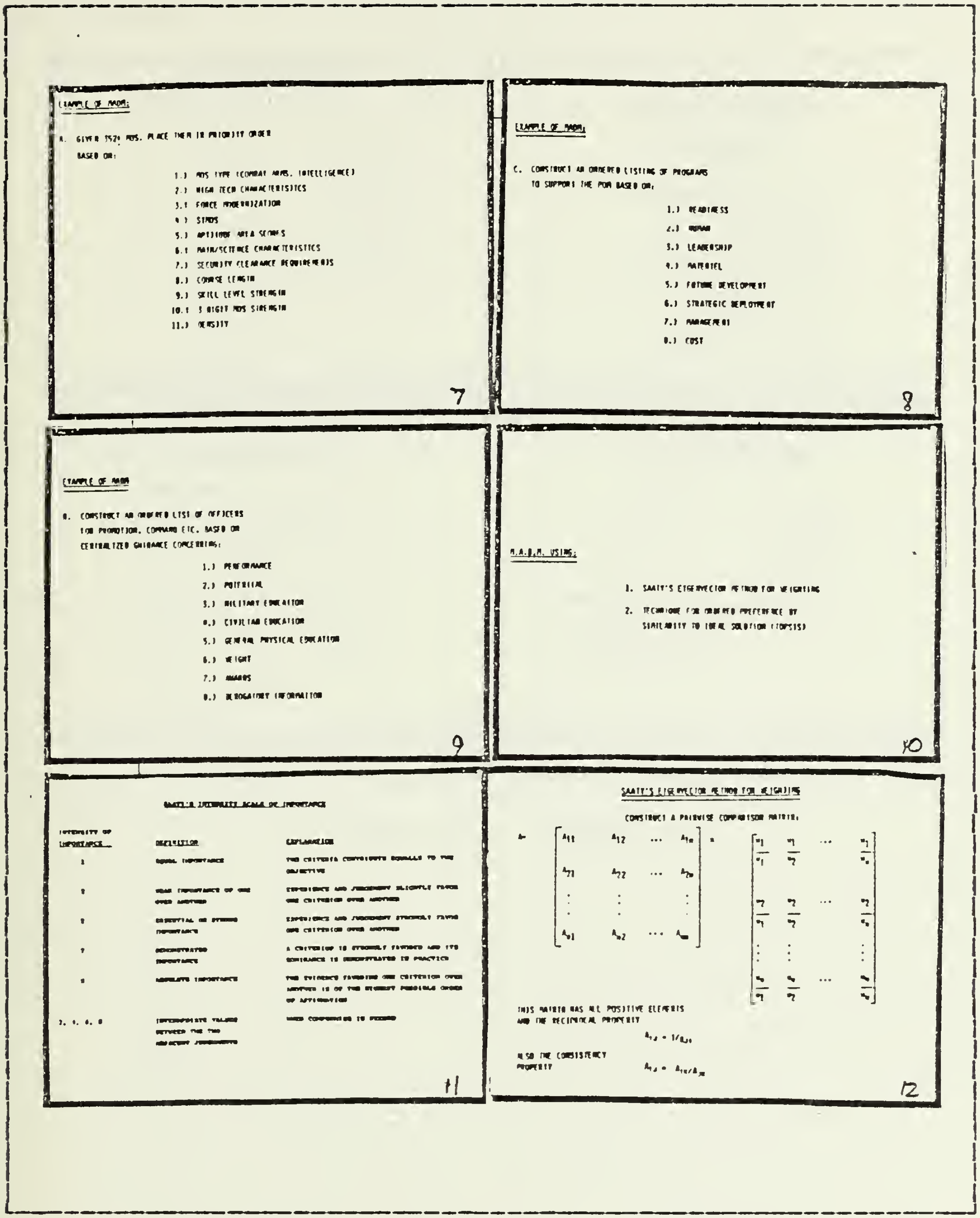
EXAMPLE OF MADM:

4. CHOOSE THE BEST HELICOPTER FROM 5 ALTERNATIVES BASED ON:

1.) CRUISE SPEED
2.) CLIMB RATE
3.) ENDURANCE
4.) PAYLOAD
5.) COST
6.) SURVIVABILITY
7.) MANEUVERABILITY
8.) RELIABILITY

6

Figure C.1 MADMAN



EXAMPLE OF MADM:

A. GIVEN 352+ MOS, PLACE THEM IN PRIORITY ORDER
BASED ON:

1.) MOS TYPE (COMBAT ARMS, INTELLIGENCE)
2.) HIGH TECH CHARACTERISTICS
3.) FORCE MODERNIZATION
4.) STMOS
5.) APTITUDE AREA SCORES
6.) MATH/SCIENCE CHARACTERISTICS
7.) SECURITY CLEARANCE REQUIREMENTS
8.) COURSE LENGTH
9.) SKILL LEVEL STRENGTH
10.) 3 DIGIT MOS STRENGTH
11.) DENSITY

EXAMPLE OF MADM:

C. CONSTRUCT AN ORDERED LISTING OF PROGRAMS
TO SUPPORT THE POM BASED ON:

1.) READINESS
2.) HUMAN
3.) LEADERSHIP
4.) MATERIEL
5.) FUTURE DEVELOPMENT
6.) STRATEGIC DEPLOYMENT
7.) MANAGEMENT
8.) COST

EXAMPLE OF MADM

B. CONSTRUCT AN ORDERED LIST OF OFFICERS
FOR PROMOTION, COMMAND ETC. BASED ON
CENTRALIZED GUIDANCE CONCERNING:

1.) PERFORMANCE
2.) POTENTIAL
3.) MILITARY EDUCATION
4.) CIVILIAN EDUCATION
5.) GENERAL PHYSICAL EDUCATION
6.) WEIGHT
7.) AWARDS
8.) DEROGATORY INFORMATION

M.A.D.M. USING:

1. SAATY'S EIGENVECTOR METHOD FOR WEIGHTING
2. TECHNIQUE FOR ORDERED PREFERENCE BY
SIMILARITY TO IDEAL SOLUTION (TOPSIS)

SAATY'S INTENSITY SCALE OF IMPORTANCE

INTENSITY OF IMPORTANCE	DEFINITION	EXPLANATION
1	EQUAL IMPORTANCE	THE CRITERIA CONTRIBUTE EQUALLY TO THE OBJECTIVE
3	WEAK IMPORTANCE OF ONE OVER ANOTHER	EXPERIENCE AND JUDGEMENT SLIGHTLY FAVOR ONE CRITERION OVER ANOTHER
5	ESSENTIAL OR STRONG IMPORTANCE	EXPERIENCE AND JUDGEMENT STRONGLY FAVOR ONE CRITERION OVER ANOTHER
7	DEMONSTRATED IMPORTANCE	A CRITERION IS STRONGLY FAVORED AND ITS DOMINANCE IS DEMONSTRATED IN PRACTICE
9	ABSOLUTE IMPORTANCE	THE EVIDENCE FAVORING ONE CRITERION OVER ANOTHER IS OF THE HIGHEST POSSIBLE ORDER OF AFFIRMATION
2, 4, 6, 8	INTERMEDIATE VALUES BETWEEN THE TWO ADJACENT JUDGEMENTS	WHEN COMPROMISE IS NEEDED

SAATY'S EIGENVECTOR METHOD FOR WEIGHTING

CONSTRUCT A PAIRWISE COMPARISON MATRIX:

$$A = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

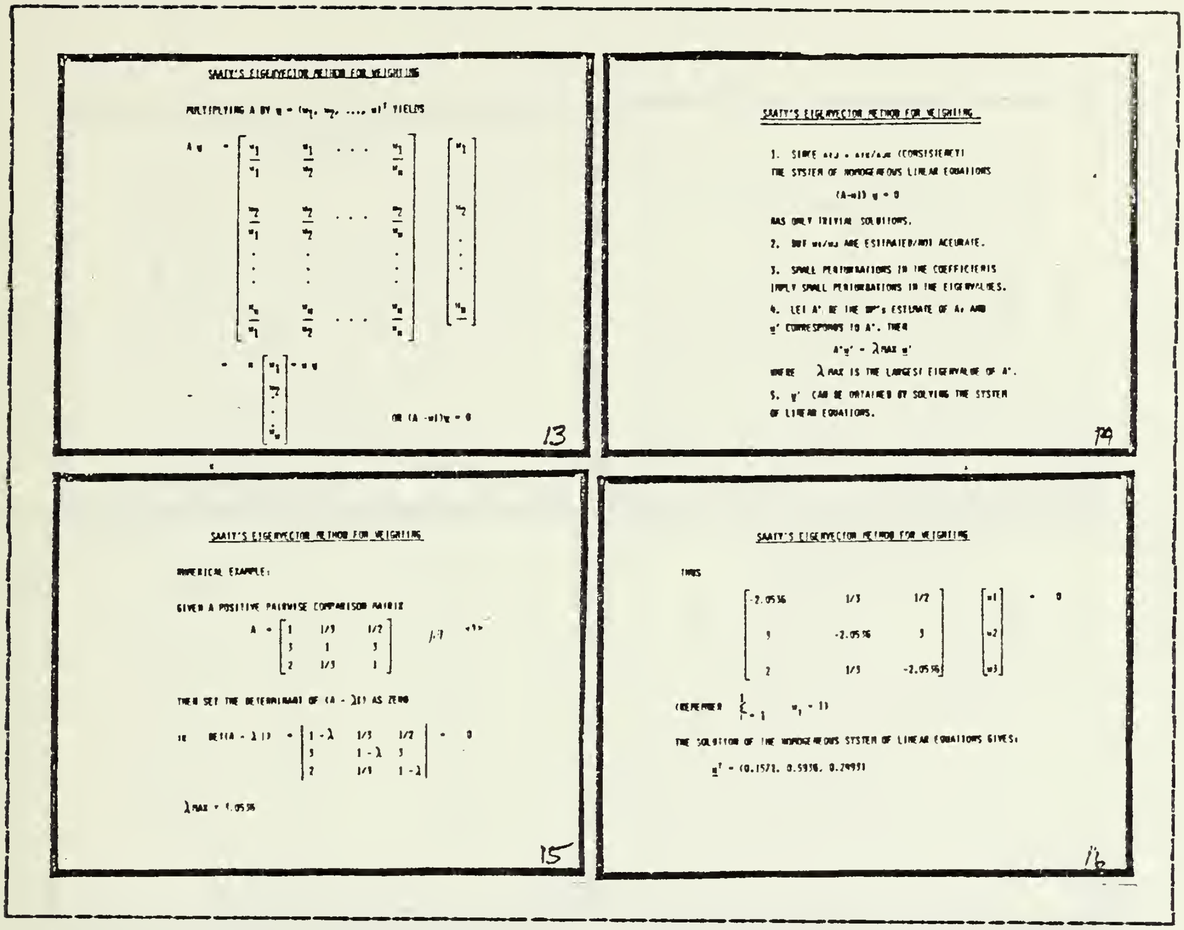
THIS MATRIX HAS ALL POSITIVE ELEMENTS
AND THE RECIPROCAL PROPERTY

$$A_{ij} = 1/a_{ji}$$

ALSO THE CONSISTENCY
PROPERTY $A_{ij} = A_{ik}/A_{jk}$

Figure C.2 MADMAN

[illegible]



SAATY'S EIGENVECTOR METHOD FOR WEIGHTING

MULTIPLYING A BY $w = (w_1, w_2, \ldots, w_n)^T$ YIELDS

$$A\,w = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

$$= n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = n\,w$$

OR $(A - nI)w = 0$

13

SAATY'S EIGENVECTOR METHOD FOR WEIGHTING

1. SINCE $a_{ij} = a_{ik}/a_{jk}$ (CONSISTENCY)
THE SYSTEM OF HOMOGENEOUS LINEAR EQUATIONS

$$(A-nI)\,w = 0$$

HAS ONLY TRIVIAL SOLUTIONS.

2. BUT w_i/w_j ARE ESTIMATED/NOT ACCURATE.

3. SMALL PERTURBATIONS IN THE COEFFICIENTS IMPLY SMALL PERTURBATIONS IN THE EIGENVALUES.

4. LET A' BE THE DM's ESTIMATE OF A, AND w' CORRESPONDS TO A'. THEN

$$A'w' = \lambda_{MAX}\, w'$$

WHERE λ_{MAX} IS THE LARGEST EIGENVALUE OF A'.

5. w' CAN BE OBTAINED BY SOLVING THE SYSTEM OF LINEAR EQUATIONS.

14

SAATY'S EIGENVECTOR METHOD FOR WEIGHTING

NUMERICAL EXAMPLE:

GIVEN A POSITIVE PAIRWISE COMPARISON MATRIX

$$A = \begin{bmatrix} 1 & 1/3 & 1/2 \\ 3 & 1 & 3 \\ 2 & 1/3 & 1 \end{bmatrix}$$

THEN SET THE DETERMINANT OF $(A - \lambda I)$ AS ZERO

$$\text{IE} \quad \text{DET}(A - \lambda I) = \begin{vmatrix} 1-\lambda & 1/3 & 1/2 \\ 3 & 1-\lambda & 3 \\ 2 & 1/3 & 1-\lambda \end{vmatrix} = 0$$

$\lambda_{MAX} = 3.0536$

15

SAATY'S EIGENVECTOR METHOD FOR WEIGHTING

THUS

$$\begin{bmatrix} -2.0536 & 1/3 & 1/2 \\ 3 & -2.0536 & 3 \\ 2 & 1/3 & -2.0536 \end{bmatrix} \begin{bmatrix} w1 \\ w2 \\ w3 \end{bmatrix} = 0$$

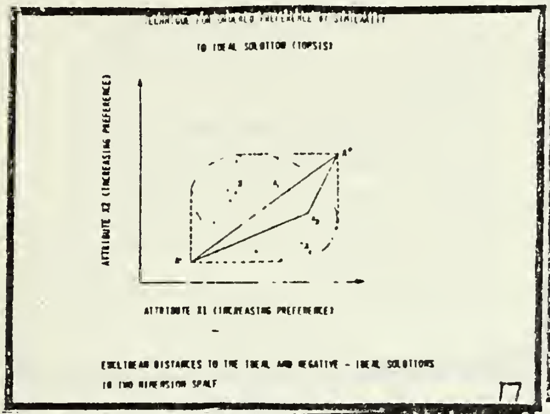
(REMEMBER $\sum_{i=1}^{3} w_i = 1$)

THE SOLUTION OF THE HOMOGENEOUS SYSTEM OF LINEAR EQUATIONS GIVES:

$w^T = (0.1571, 0.5936, 0.2993)$

16

Figure C.3 MADMAN



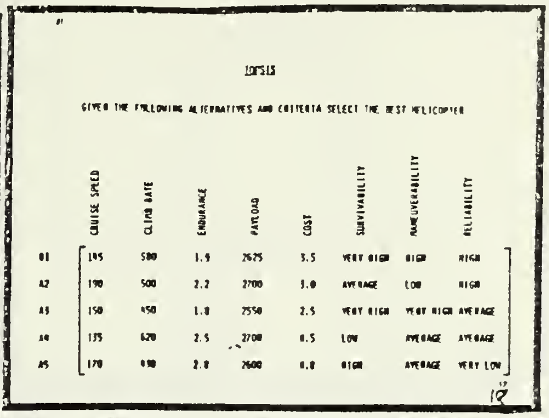
TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY

TO IDEAL SOLUTION (TOPSIS)

ATTRIBUTE X2 (INCREASING PREFERENCE)
A*
A-
ATTRIBUTE X1 (INCREASING PREFERENCE)

EUCLIDEAN DISTANCES TO THE IDEAL AND NEGATIVE - IDEAL SOLUTIONS IN TWO DIMENSION SPACE

17

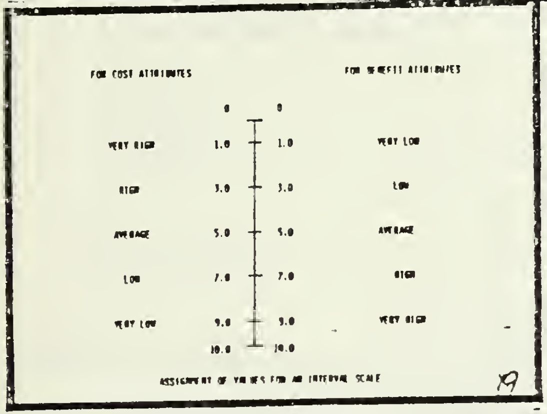


TOPSIS

GIVEN THE FOLLOWING ALTERNATIVES AND CRITERIA SELECT THE BEST HELICOPTER

	CRUISE SPEED	CLIMB RATE	ENDURANCE	PAYLOAD	COST	SURVIVABILITY	MANEUVERABILITY	RELIABILITY
A1	145	580	1.9	2625	3.5	VERY HIGH	HIGH	HIGH
A2	190	500	2.2	2700	3.0	AVERAGE	LOW	HIGH
A3	150	450	1.8	2550	2.5	VERY HIGH	VERY HIGH	AVERAGE
A4	135	620	2.5	2700	4.5	LOW	AVERAGE	AVERAGE
A5	170	430	2.0	2600	4.0	HIGH	AVERAGE	VERY LOW

18

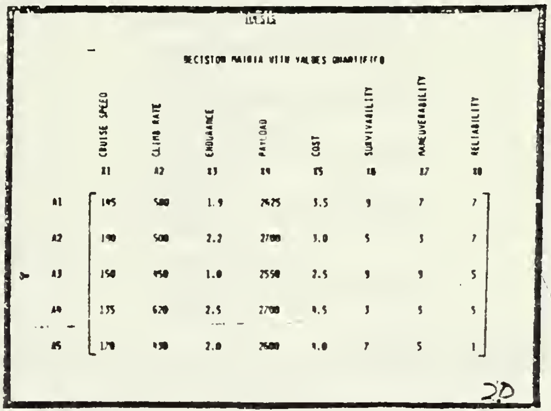


FOR COST ATTRIBUTES

FOR BENEFIT ATTRIBUTES

ASSIGNMENT OF VALUES FOR AN INTERVAL SCALE

19

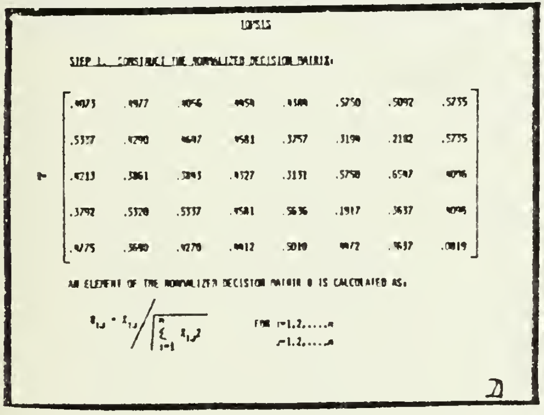


TOPSIS

DECISION MATRIX WITH VALUES QUANTIFIED

	CRUISE SPEED X1	CLIMB RATE X2	ENDURANCE X3	PAYLOAD X4	COST X5	SURVIVABILITY X6	MANEUVERABILITY X7	RELIABILITY X8
D= A1	145	580	1.9	2625	3.5	9	7	7
A2	190	500	2.2	2700	3.0	5	3	7
A3	150	450	1.8	2550	2.5	9	9	5
A4	135	620	2.5	2700	4.5	3	5	5
A5	170	430	2.0	2600	4.0	7	5	1

20



TOPSIS

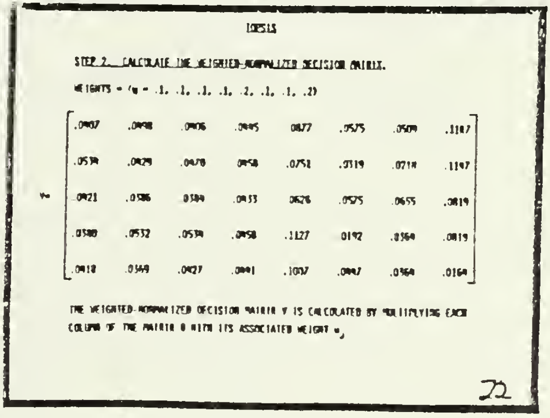
STEP 1. CONSTRUCT THE NORMALIZED DECISION MATRIX:

$$R = \begin{bmatrix} .4073 & .4977 & .4056 & .4454 & .4384 & .5750 & .5092 & .5735 \\ .5337 & .4290 & .4697 & .4581 & .3757 & .3194 & .2182 & .5735 \\ .4213 & .3861 & .3843 & .4327 & .3131 & .5750 & .6547 & .4096 \\ .3792 & .5320 & .5337 & .4581 & .5636 & .1917 & .3637 & .4096 \\ .4775 & .3690 & .4270 & .4412 & .5010 & .4472 & .3637 & .0819 \end{bmatrix}$$

AN ELEMENT OF THE NORMALIZED DECISION MATRIX R IS CALCULATED AS:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{m} x_{ij}^2} \qquad \text{FOR } i=1,2,\ldots,m \quad j=1,2,\ldots,n$$

21



TOPSIS

STEP 2. CALCULATE THE WEIGHTED-NORMALIZED DECISION MATRIX.

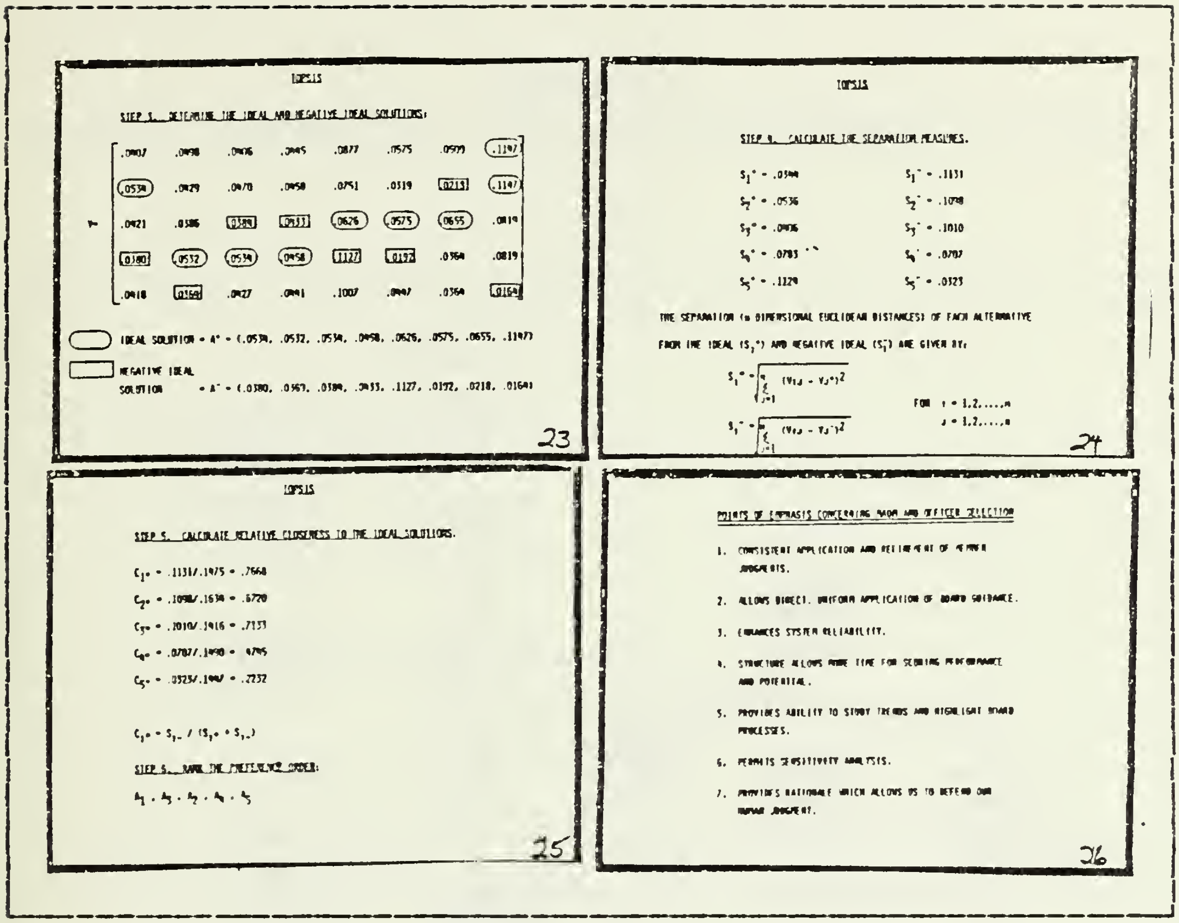
WEIGHTS = (w = .1, .1, .1, .1, .2, .1, .1, .2)

$$V = \begin{bmatrix} .0407 & .0498 & .0406 & .0445 & .0877 & .0575 & .0509 & .1147 \\ .0534 & .0429 & .0470 & .0458 & .0751 & .0319 & .0218 & .1147 \\ .0421 & .0386 & .0384 & .0433 & .0626 & .0575 & .0655 & .0819 \\ .0380 & .0532 & .0534 & .0458 & .1127 & .0192 & .0364 & .0819 \\ .0478 & .0369 & .0427 & .0441 & .1002 & .0447 & .0364 & .0164 \end{bmatrix}$$

THE WEIGHTED-NORMALIZED DECISION MATRIX V IS CALCULATED BY MULTIPLYING EACH COLUMN OF THE MATRIX R WITH ITS ASSOCIATED WEIGHT w_j

22

Figure C.4 MADMAN



TOPSIS

STEP 3. DETERMINE THE IDEAL AND NEGATIVE IDEAL SOLUTIONS:

$$V = \begin{bmatrix} .0407 & .0498 & .0406 & .0445 & .0877 & .0575 & .0599 & .1197 \\ .0534 & .0429 & .0470 & .0450 & .0751 & .0319 & \boxed{.0218} & .1197 \\ .0421 & .0386 & \boxed{.0389} & \boxed{.0433} & .0626 & .0575 & .0655 & .0819 \\ \boxed{.0380} & .0532 & .0534 & .0458 & \boxed{.1127} & \boxed{.0192} & .0364 & .0819 \\ .0418 & \boxed{.0567} & .0427 & .0441 & .1007 & .0447 & .0364 & \boxed{.0164} \end{bmatrix}$$

IDEAL SOLUTION = A^* = (.0534, .0532, .0534, .0458, .0626, .0575, .0655, .1197)

▭ NEGATIVE IDEAL SOLUTION = A^- = (.0380, .0567, .0389, .0433, .1127, .0192, .0218, .0164)

23

TOPSIS

STEP 4. CALCULATE THE SEPARATION MEASURES.

$S_1^* = .0344$ $S_1^- = .1131$

$S_2^* = .0536$ $S_2^- = .1098$

$S_3^* = .0406$ $S_3^- = .1010$

$S_4^* = .0783$ $S_4^- = .0707$

$S_5^* = .1124$ $S_5^- = .0323$

THE SEPARATION (n DIMENSIONAL EUCLIDEAN DISTANCES) OF EACH ALTERNATIVE FROM THE IDEAL (S_i^*) AND NEGATIVE IDEAL (S_i^-) ARE GIVEN BY:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^*)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2}$$

FOR $i = 1, 2, \ldots, m$
$j = 1, 2, \ldots, n$

24

TOPSIS

STEP 5. CALCULATE RELATIVE CLOSENESS TO THE IDEAL SOLUTIONS.

$C_{1*} = .1131/.1475 = .7668$

$C_{2*} = .1098/.1634 = .6720$

$C_{3*} = .1010/.1416 = .7133$

$C_{4*} = .0707/.1490 = .4745$

$C_{5*} = .0323/.1447 = .2232$

$C_{i*} = S_{i-} / (S_{i*} + S_{i-})$

STEP 6. RANK THE PREFERENCE ORDER:

$A_1 > A_3 > A_2 > A_4 > A_5$

25

POINTS OF EMPHASIS CONCERNING MADM AND OFFICER SELECTION

1. CONSISTENT APPLICATION AND REFINEMENT OF MEMBER JUDGMENTS.
2. ALLOWS DIRECT, UNIFORM APPLICATION OF BOARD GUIDANCE.
3. ENHANCES SYSTEM RELIABILITY.
4. STRUCTURE ALLOWS MORE TIME FOR SCORING PERFORMANCE AND POTENTIAL.
5. PROVIDES ABILITY TO STUDY TRENDS AND HIGHLIGHT BOARD PROCESSES.
6. PERMITS SENSITIVITY ANALYSIS.
7. PROVIDES RATIONALE WHICH ALLOWS US TO DEFEND OUR HUMAN JUDGMENT.

26

Figure C.5 MADMAN

APPENDIX D

COMMAND STRUCTURE AND FORCE DEPLOYMENT INTACS AND COMSR

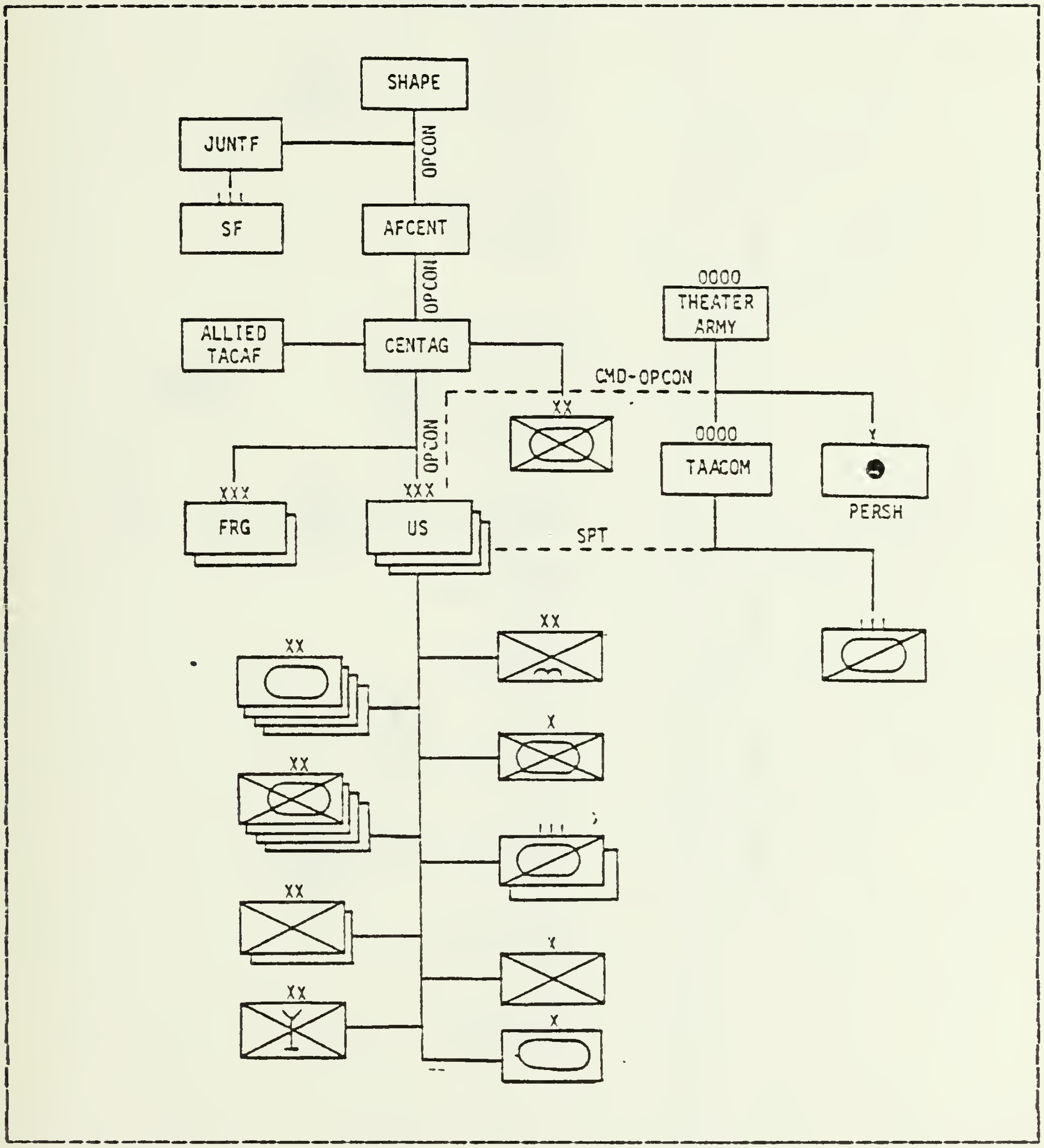


Figure D.1 INTACS and COMSR Command Structure

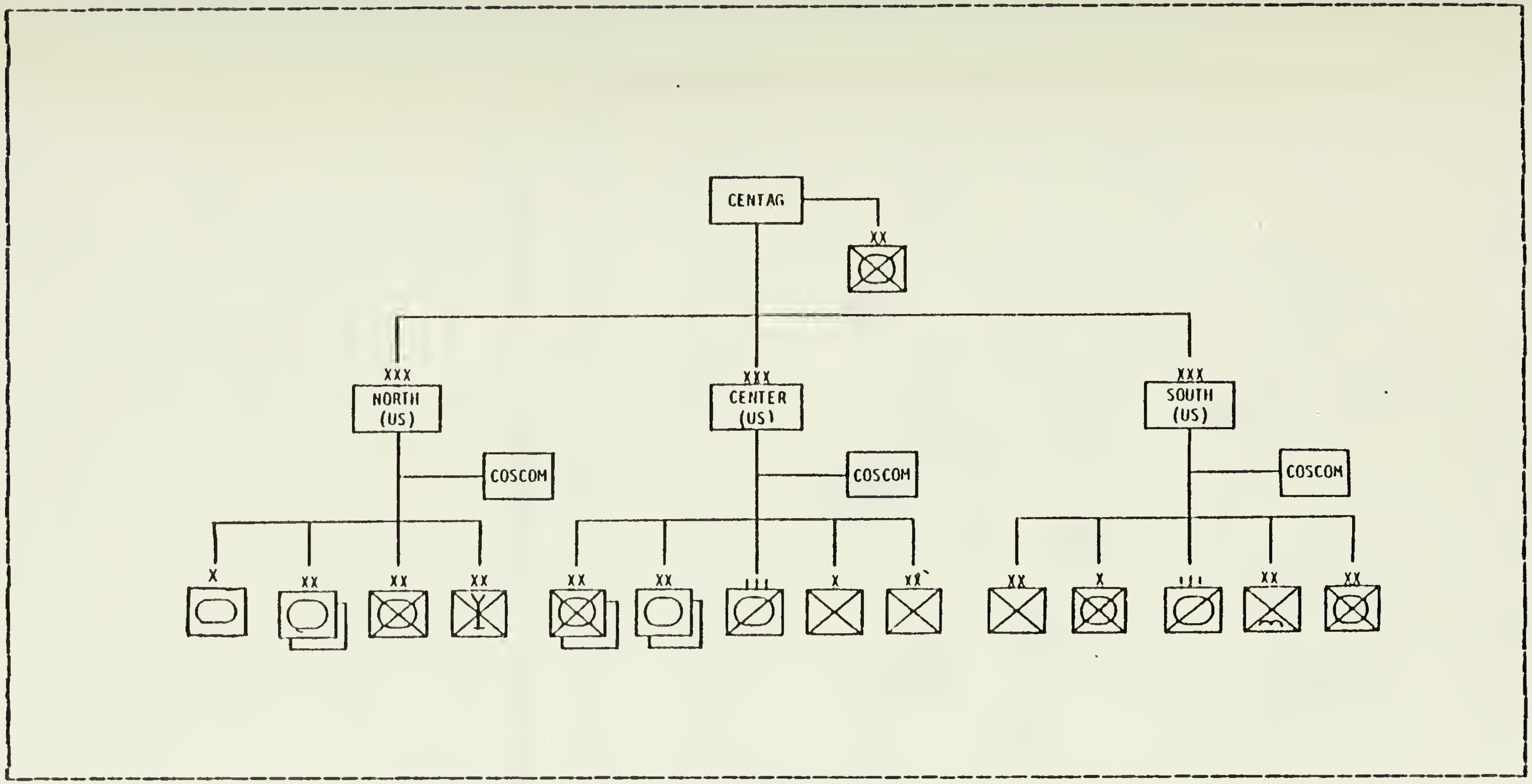


Figure D.2 INTACS and COMSR Task Organization

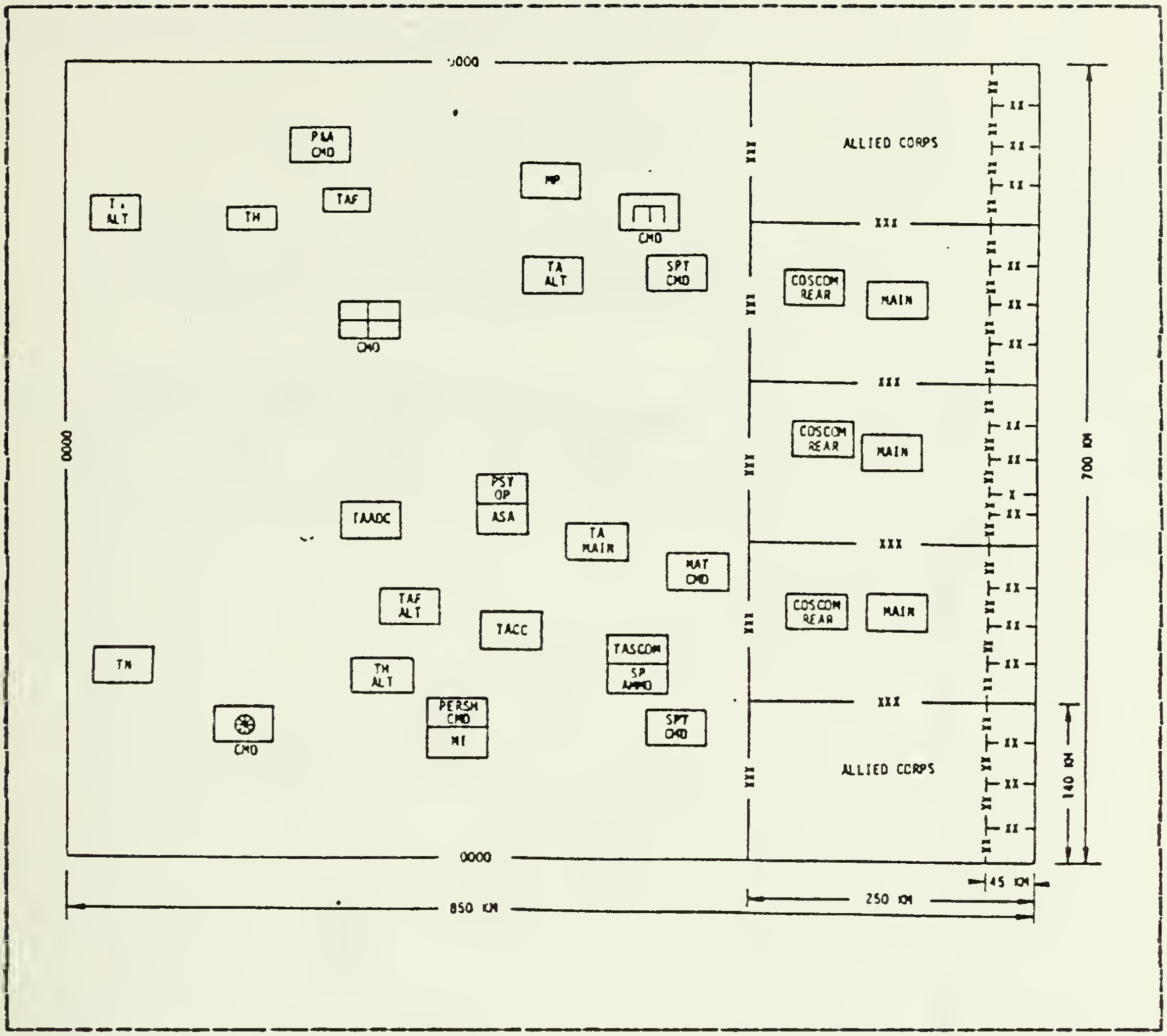


Figure D.3 TO&E Units in COMSR Database Theater

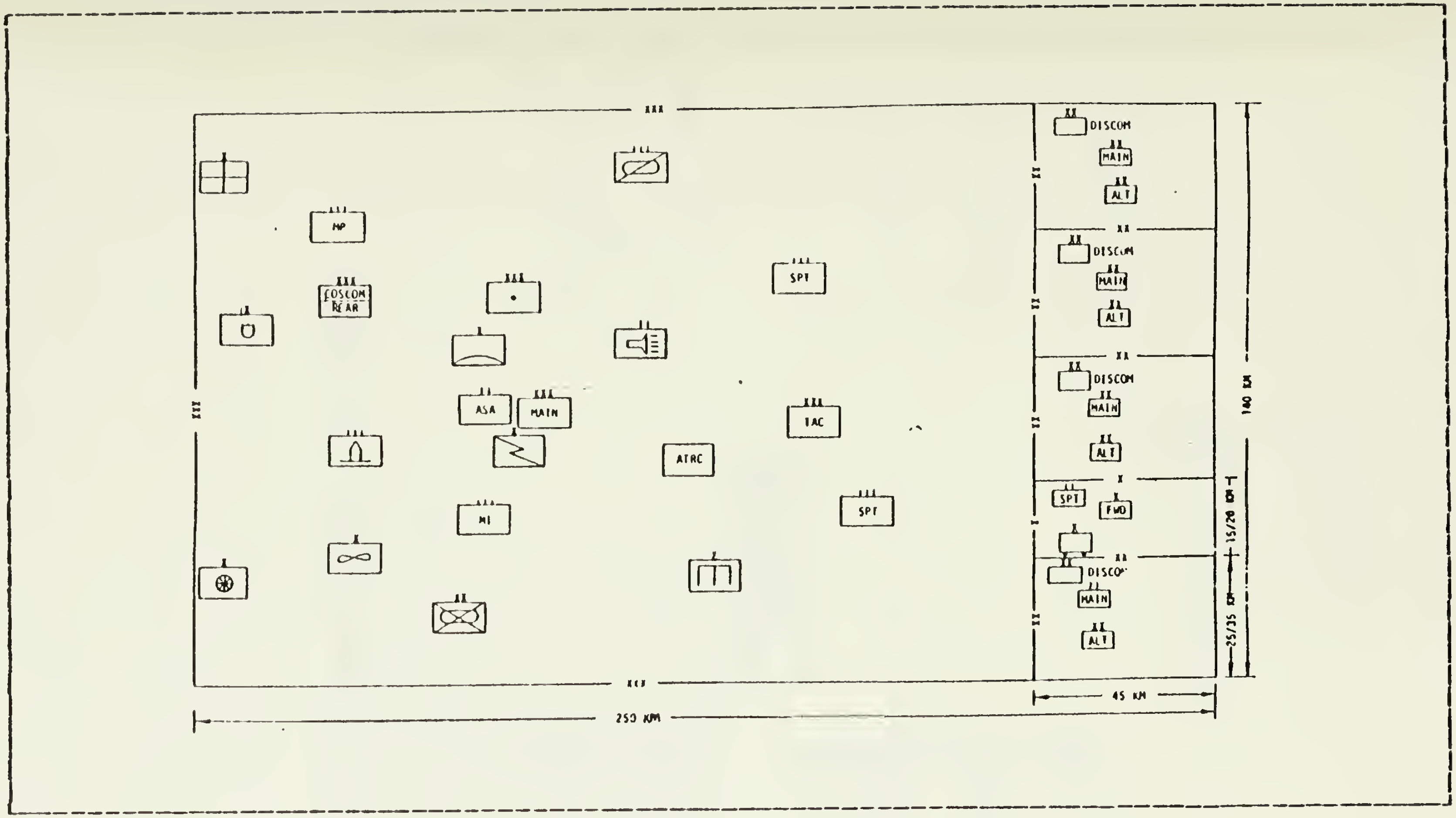
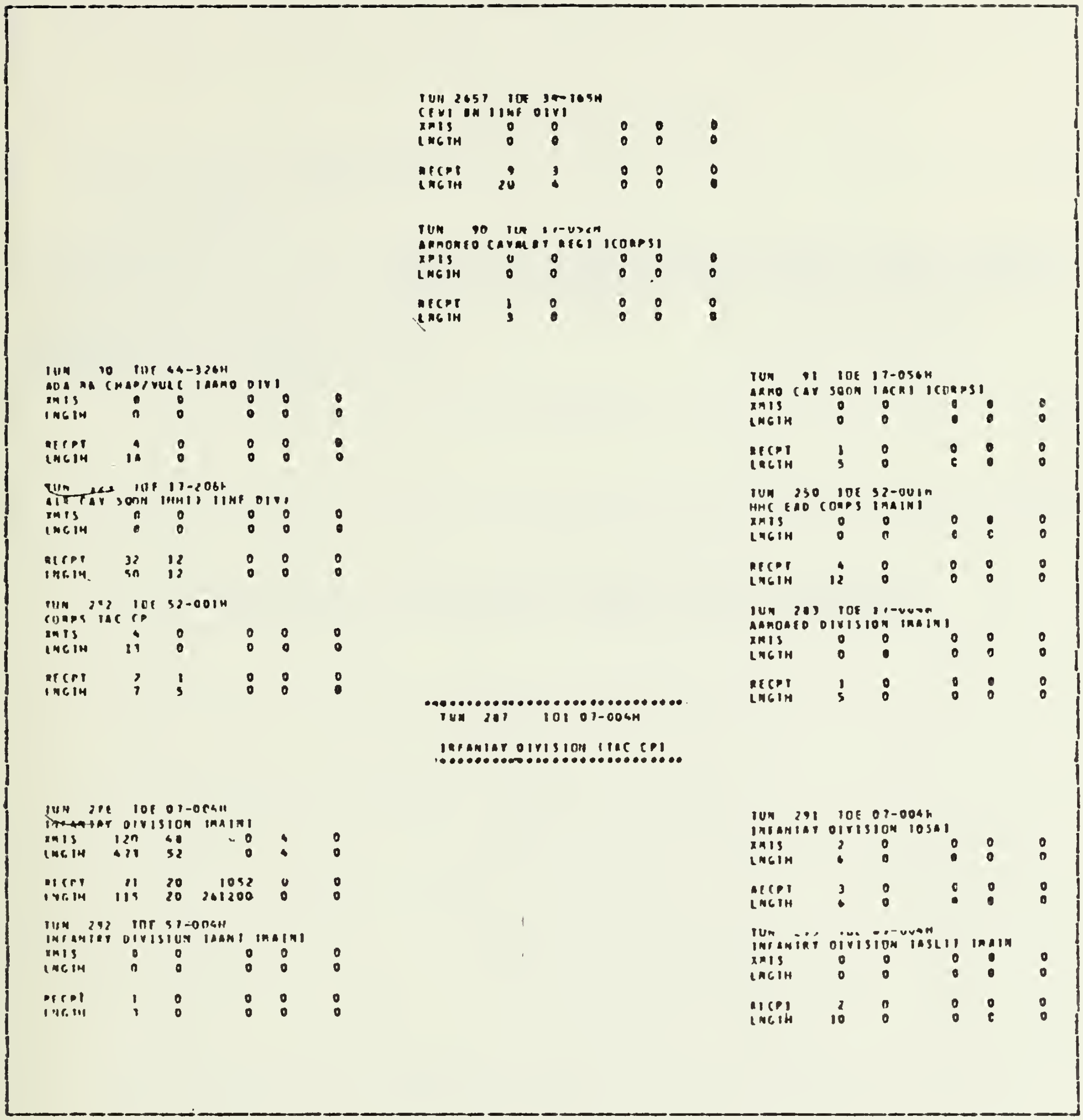
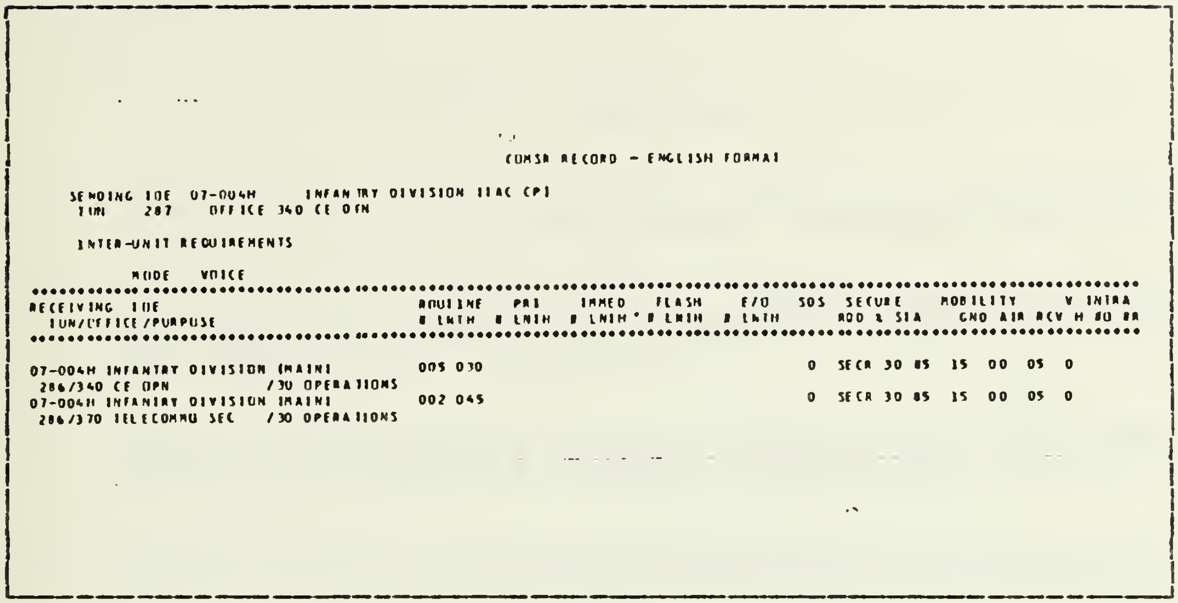


Figure D.4 TO&E Units in COMSR Database Corps



```
TUN 2657   TOE 34-165H
CEWI BN (INF DIV)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       9     3        0    0       0
LNGTH      20     4        0    0       0

TUN   90   TOE 17-052H
ARMORED CAVALRY REGT (CORPS)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       1     0        0    0       0
LNGTH       3     0        0    0       0


TUN   10   TOE 44-326H
ADA BN CHAP/VULC (ARMD DIV)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       4     0        0    0       0
LNGTH      18     0        0    0       0

TUN [illegible]  TOE 17-206H
AIR CAV SQDN (HHT) (INF DIV)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT      32    12        0    0       0
LNGTH      50    12        0    0       0

TUN  2?2   TOE 52-001H
CORPS TAC CP
XMTS        4     0        0    0       0
LNGTH      13     0        0    0       0

RECPT       2     1        0    0       0
LNGTH       7     5        0    0       0


TUN   91   TOE 17-056H
ARMD CAV SQDN (ACR) (CORPS)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       1     0        0    0       0
LNGTH       5     0        0    0       0

TUN  250   TOE 52-001H
HHC EAD CORPS (MAIN)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       4     0        0    0       0
LNGTH      12     0        0    0       0

TUN  283   TOE 17-[illegible]
ARMORED DIVISION (MAIN)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       1     0        0    0       0
LNGTH       5     0        0    0       0


******************************
  TUN  287     TOE 07-004H

  INFANTRY DIVISION (TAC CP)
******************************


TUN  2?8   TOE 07-004H
INFANTRY DIVISION (MAIN)
XMTS      120    48        0    4       0
LNGTH     473    52        0    4       0

RECPT      71    20     1052    0       0
LNGTH     115    20   261200    0       0

TUN  292   TOE 57-004H
INFANTRY DIVISION (ABN) (MAIN)
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       1     0        0    0       0
LNGTH       3     0        0    0       0


TUN  291   TOE 07-004H
INFANTRY DIVISION (DSA)
XMTS        2     0        0    0       0
LNGTH       6     0        0    0       0

RECPT       3     0        0    0       0
LNGTH       6     0        0    0       0

TUN [illegible]  TOE 07-004H
INFANTRY DIVISION (ASLT) (MAIN
XMTS        0     0        0    0       0
LNGTH       0     0        0    0       0

RECPT       2     0        0    0       0
LNGTH      10     0        0    0       0
```

Figure D.5   COMSR Bubble Output



```
                                                COMSR RECORD - ENGLISH FORMAT

     SENDING IDE  07-004H      INFANTRY DIVISION (TAC CP)
      TUN    287    OFFICE 340 CE OPN

      INTER-UNIT REQUIREMENTS

             MODE    VOICE
*****************************************************************************************************
RECEIVING  IDE                              ROUTINE   PRI    IMMED   FLASH    F/O   SOS  SECURE     MOBILITY     V INTRA
  TUN/OFFICE/PURPOSE                        # LNTH  # LNTH  # LNTH * # LNTH  # LNTH      ROD & STA    GND AIR RCV H #O RR
*****************************************************************************************************

07-004H INFANTRY DIVISION (MAIN)            005 030                                 0   SECR 30 85   15  00  05  0
 286/340 CE OPN            /30 OPERATIONS
07-004H INFANTRY DIVISION (MAIN)            002 045                                 0   SECR 30 85   15  00  05  0
 286/370 TELECOMMU SEC     /30 OPERATIONS
```

Figure D.6   Current COMSR Data Elements

LIST OF REFERENCES

1. Morris, W., et al, The American Heritage Dictionary, American Heritage Publishing Co., New York, 1970.

2. US Army Intelligence School, Soviet Army Operations and Tactics, Coordinating Draft, FM 100-2-1, Ft. Huachuca, Arizona, August 82.

3. US Army Intelligence School, Soviet Army Specialized Warfare and Rear Area Support, Coordinating Draft, FM 100-2-2, Ft. Huachuca, Arizona, August 82.

4. Blanchard, B.S., Logistics Engineering and Management, 2nd Ed., Prentice Hall, Englewood Cliffs, N.J., 1981.

5. Savkin, D., Basic Principles of Operational Art and Tactics, Voyenny, Moscow, 1968.

6. Douglass, J. D., Soviet Military Strategy in Europe, New York, Pergamon Press, 1980.

7. Frolov, V.S., "The Computer in Troop Control ", Soviet Cybernetics Journal, Moscow, 1973.

8. Riordan, J.,Delay Curves for Calls Served at Random, The Bell System Technical Journal, Vol.XXXII #1, 1953.

9. Wilkerson, R., Exponential Calls Served in Random Order, The Bell System Technical Journal, Vol.XXXII #2, 1953.

10. Beckmann, P., Introduction to Elementary Queing Theory and Telephone Traffic Theory, Golem, Colorado, 1968.

11. Kleinrock, L., Stochastic Message Flow and Delay, Dover, New York, 1964.

12. Cohen, M.D., Draft: Artificial Intelligence and the Dynamic Performance of Organizational Designs, NPS/Stamford University Joint Workshop, Feb 84.

13. Weissinger-Baylon, Garbage Can Decision Making In Naval Warfare, NPS/Stamford University Joint Workshop, Feb 84.

14. Field Manual 11-50, Combat Communications Within the Division, Headquarters DA, 1 Nov 78, USA Signal School, Ft. Gordon, Ga.

15. Neal, D., Classnotes, Manpower Requirements Analysis, Naval Postgraduate School, Feb 1984.

16. Lawson, J., Examining the "Garbage Can" Model, NPS/Stamford Joint Workshop, Feb 84.

17. Marcello, J., Maj. TOPSIS Program Multiattribute Decision Making Process, Headquarters DA MILPERCEN, 1983.

18. Field Manual 11-92, Combat Communications Within the Corps, Headquarters DA, 1 Nov 78, USA Signal School, Ft. Gordon, Ga.

19. CCMSR Technical Operations Element, Communications Support Requirements Data Base Instruction Booklet, USA Signal School, Ft. Gordon, Ga. 1973.

20. Zeleny, M., Multiple Criteria Decision Making, McGraw-Hill, New York, 1982.

21. Hwang, C L., Multi-attribute Decision Making Methods and Applications, Springer Publications, Berlin, 1981.

22. Saaty, T.L., Decision Making For Leaders, Lifetime Learning Publications, Belmont, Cal., 1982

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